ALCOA ALUMINUM AND ITS ALLOYS

ALCOA

[BLANK PAGE]

INTERNATIONAL

CCA

ALCOA ALUMINUM AND ITS ALLOYS

ALUMINUM COMPANY OF AMERICA

PITTSBURGH • PENNSYLVANIA

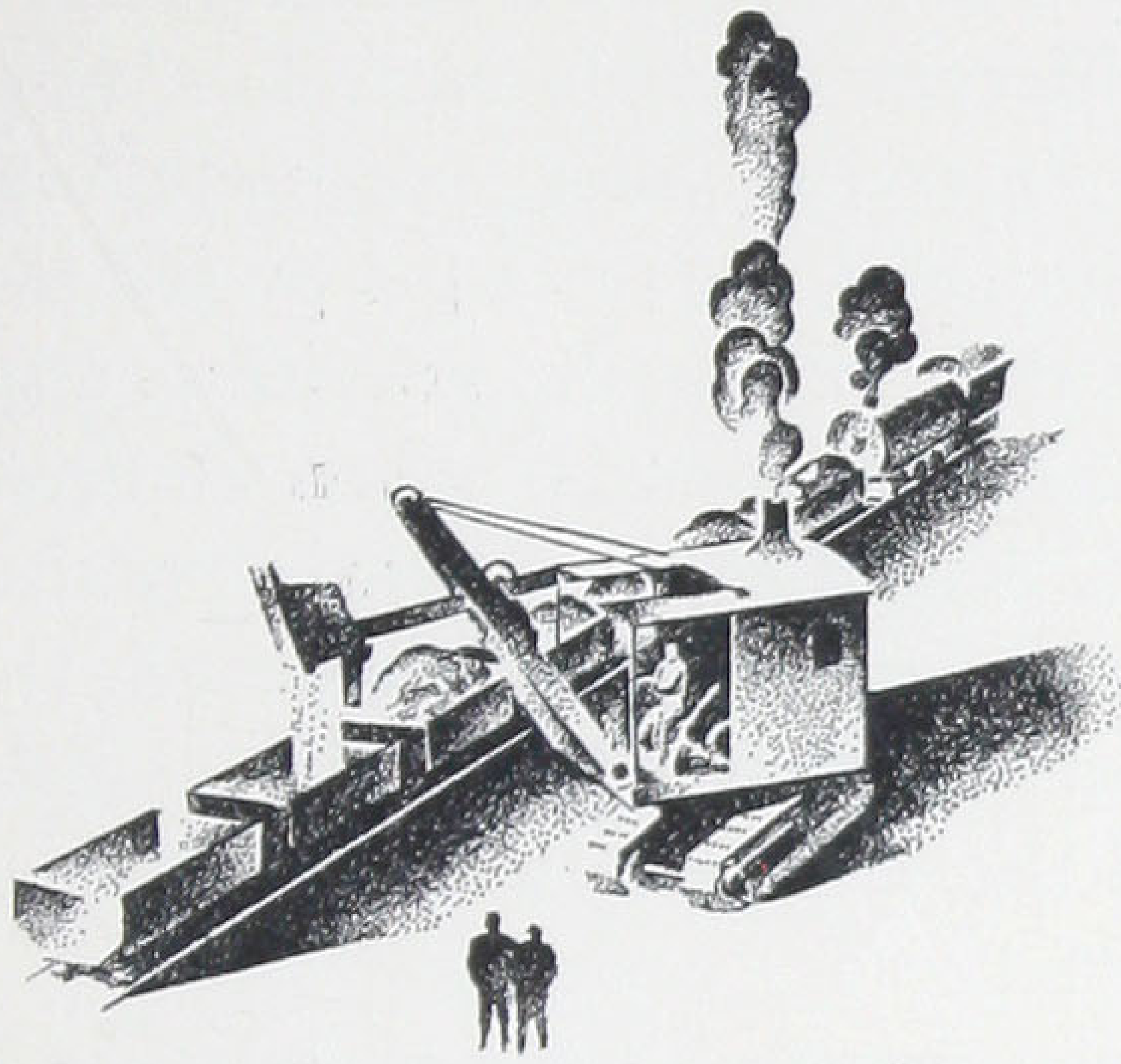
(1936)

FOREWORD

There is a rapidly growing demand for information concerning the properties of aluminum—one of the newest of the structural metals.

The number of alloys has grown to such an extent that the designing engineer is sometimes at a loss to know which one to choose. No two of the alloys have identical properties and for each application some one alloy is best suited. It is also necessary to know the forms in which these materials are available and the sizes that are in commercial production.

It is the purpose of this booklet to present in concise form some of the fundamental information concerning the alloys which are produced by Aluminum Company of America.



GENERAL INFORMATION

THE MOST STRIKING quality of aluminum, among its many useful properties, is the fact that it weighs about one-third as much as other commonly-used metals. This advantage is retained in its commercial alloys, some of which are actually lighter than pure aluminum.

Combined with the low specific gravity of aluminum are many other desirable characteristics which have made aluminum the fifth most commonly-used metal today, both in point of tonnage and volume. Chief among these are: high resistance to the corrosive action of the atmosphere and a great variety of chemical compounds; high thermal and electrical conductivity; high reflectivity for radiant energy, from the short wave lengths of ultraviolet to the longer waves of heat and electromagnetic or radio waves; and ease of fabrication. Aluminum can be welded by all commercial methods (See page 25). Its compounds are colorless and are without harmful action upon the human system. While ordinarily quite inert, at very high temperatures or in the presence of certain chemicals, notably strong alkalis, aluminum is a strong reducing agent and is used to reduce refractory metals from their ores and to remove gases from molten steel.

While considering the properties of aluminum in relation to its various applications, attention should be called to the advantages resulting from the lightness of the metal even in those cases where this quality has no direct bearing on the usefulness of the product.

Comparisons of costs should be made on the finished article as made from the different possible materials, not on their relative prices per pound. Since the volume of metal commonly used will be substantially the same, the price per pound of aluminum should be divided by the ratio of specific gravities (approximately three for most of the common metals) when comparing the material costs. In addition, economies frequently result from the greater ease with which aluminum can be fabricated, the greater production and lower cost of distribution made possible by the lightness of the metal, and the ease with which the metal can be polished or otherwise finished.

Frequently, these economies are more than sufficient to overcome an unfavorable cost comparison from the standpoint of metal value alone, as, for example, with common grades of steel. In such comparisons, the higher scrap value of aluminum when the article is finally discarded is always an advantage to be considered in the choice of the metal to be used.

Aluminum of commercial purity may contain up to one per cent of other elements, principally iron and silicon, as impurities. This is the grade which is commonly used, although for certain special applications, metal of higher purity is required.

Commercially pure aluminum in the annealed or the cast condition has relatively low mechanical properties; its tensile strength is approximately one-fourth to one-fifth that of structural steel. The strength may be more than doubled by working the metal cold, that is, by strain-hardening, after the cast structure of the ingot has been broken down by hot working. This gain in strength is accompanied by a loss in the ductility of the metal; the forming qualities are decreased as the amount of cold working is increased.

The addition of other metals to form alloys offers another means of increasing the strength and hardness of aluminum. The small percentage of impurities in commercial aluminum is sufficient to increase the strength, compared with that of pure aluminum, about 50 per cent.

The metals most commonly used in the production of commercial aluminum alloys are copper, silicon, manganese, magnesium, chromium, iron, zinc and nickel. These elements may be added singly, or some combination of them may be used to produce the desired characteristics in the resulting alloy. If the alloy is to be

manufactured in wrought forms, the total percentage of alloying elements is seldom more than six or seven per cent, although in casting alloys, appreciably higher percentages are frequently used.

The tensile strength of the aluminum alloys in the cast or the annealed condition varies, depending upon their composition, up to values about double that of commercial aluminum. The wrought alloys may have their strength further increased by cold working. The gain in strength which results from alloying and strain-hardening is accompanied by a decrease in the ductility of the metal, although the properties which result are more than adequate for a great variety of commercial applications.

Some years ago, the discovery was made that certain of the aluminum alloys, when subjected to appropriate heat-treatment processes, showed remarkable increases in tensile and yield strength and hardness. The elongation, in some instances, was also increased over that of the annealed alloy. The combination of alloying and heat-treatment processes has made available a series of aluminum alloys having strengths comparable with those of structural steel, while retaining in large measure the characteristic qualities of the parent metal. Both wrought and cast alloys which respond to the heat-treatment operations have been developed, but the improvement is more pronounced in the case of the alloys in which the cast structure has been broken up by working the metal.

With the development of this class of alloys, the enumeration of desirable qualities of aluminum may be augmented to include excellent mechanical properties. "Aluminum" is used here in its popular sense, that is, not only commercially pure aluminum, but the light alloys in which aluminum is the principal constituent. The remarkable development in the aluminum industry, in the past few years, must be attributed to the strides which have been made in the structural applications of the light, strong alloys.

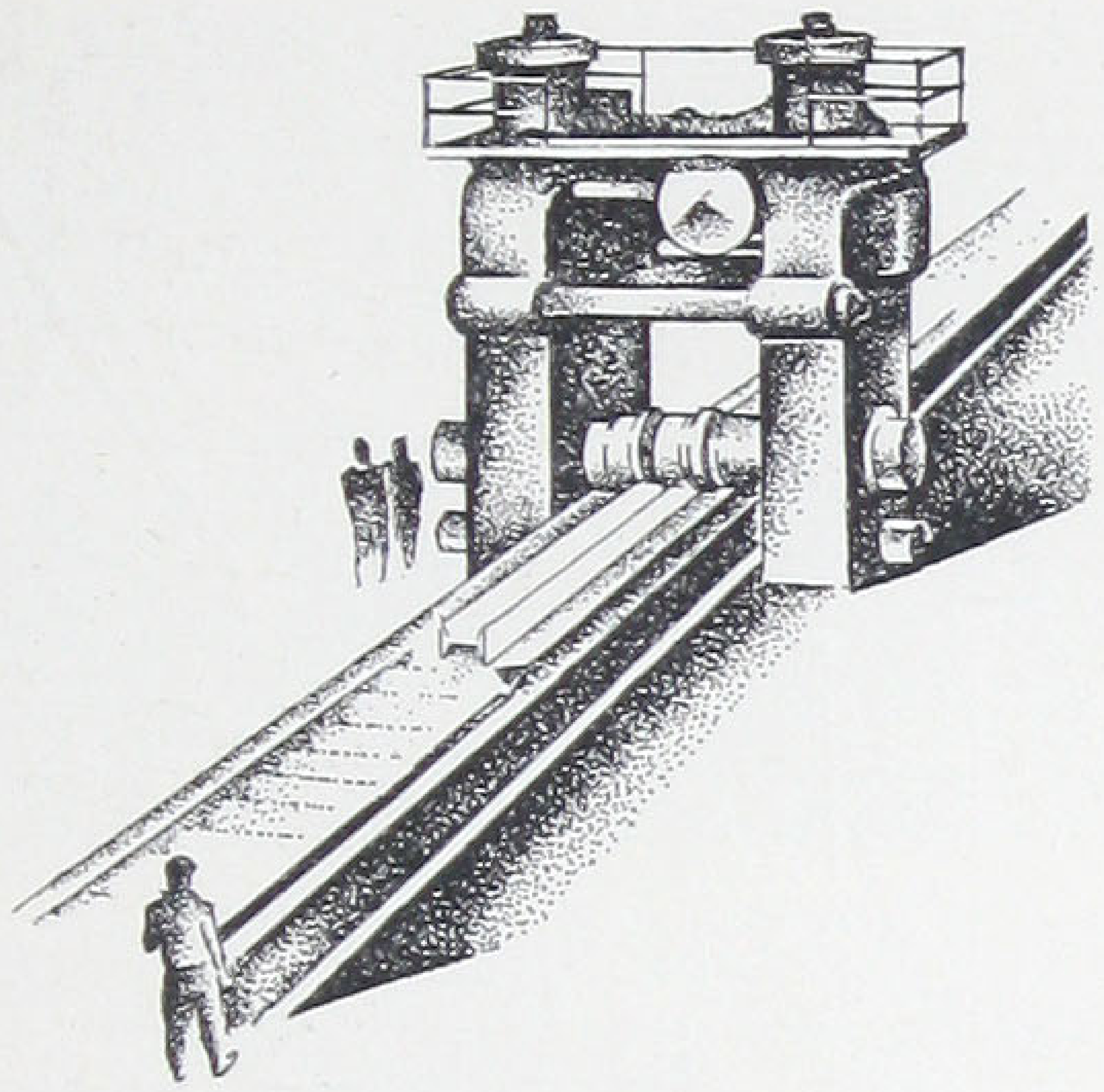
The change in strength which is accomplished by the alloying of other metals with aluminum is accompanied by changes in the other properties of the metal. They are seldom, if ever, the same in the different alloys, with the result that several alloys may have substantially the same tensile strength, but differ

widely in yield strength, resistance to corrosion, thermal and electrical conductivity, the ease with which they can be cast or fabricated, or in other qualities upon which their various applications depend. For many purposes, considerations other than strength are the deciding factors in the choice of the material.

The properties which are required in a material, as well as the qualities which may be sacrificed without serious handicap, vary widely with the use that is to be made of it. A considerable number of commercial alloys has been developed, each of which is designed to meet the requirements of a certain type of application. The compromise, which is practically always necessary in choosing any material, is thus reduced to a minimum.

The fabrication of an alloy into the products required in industrial applications generally becomes more difficult as the mechanical properties of the alloy are increased. The fabricating characteristics of a material are, obviously, reflected in its selling price, a factor which is usually of importance in the selection of a material.

The ease of manufacture varies with the nature of the commercial manufacturing process; for example, some alloys having valuable properties may be readily rolled into plate and sheet, but present difficulties in the manufacture of tubing or forgings which would make their cost prohibitive. Other alloys may be developed primarily to overcome such manufacturing problems. While aluminum alloys having a wide range of mechanical properties are available in practically all the forms in which metals are produced, not all of the alloys are available in all of these forms. The tables of commercial sizes for the various commodities on pages 55 to 89 indicate the alloys in which they are regularly manufactured. In some instances, other alloys can also be produced where required for specific purposes. Such cases should be taken up with the sales representatives of Aluminum Company of America.

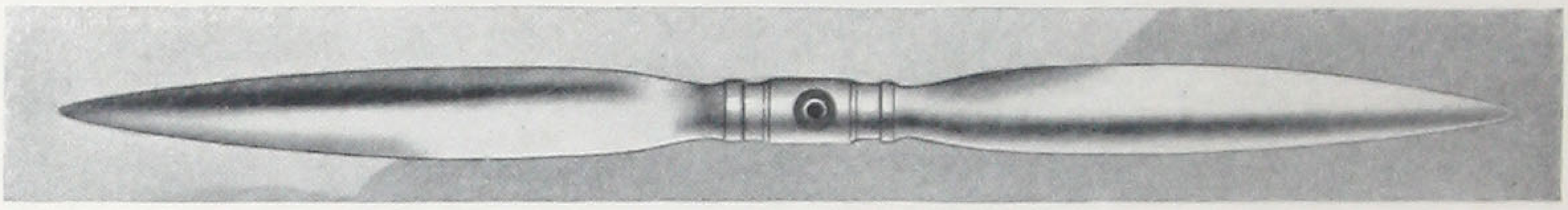


WROUGHT ALLOYS

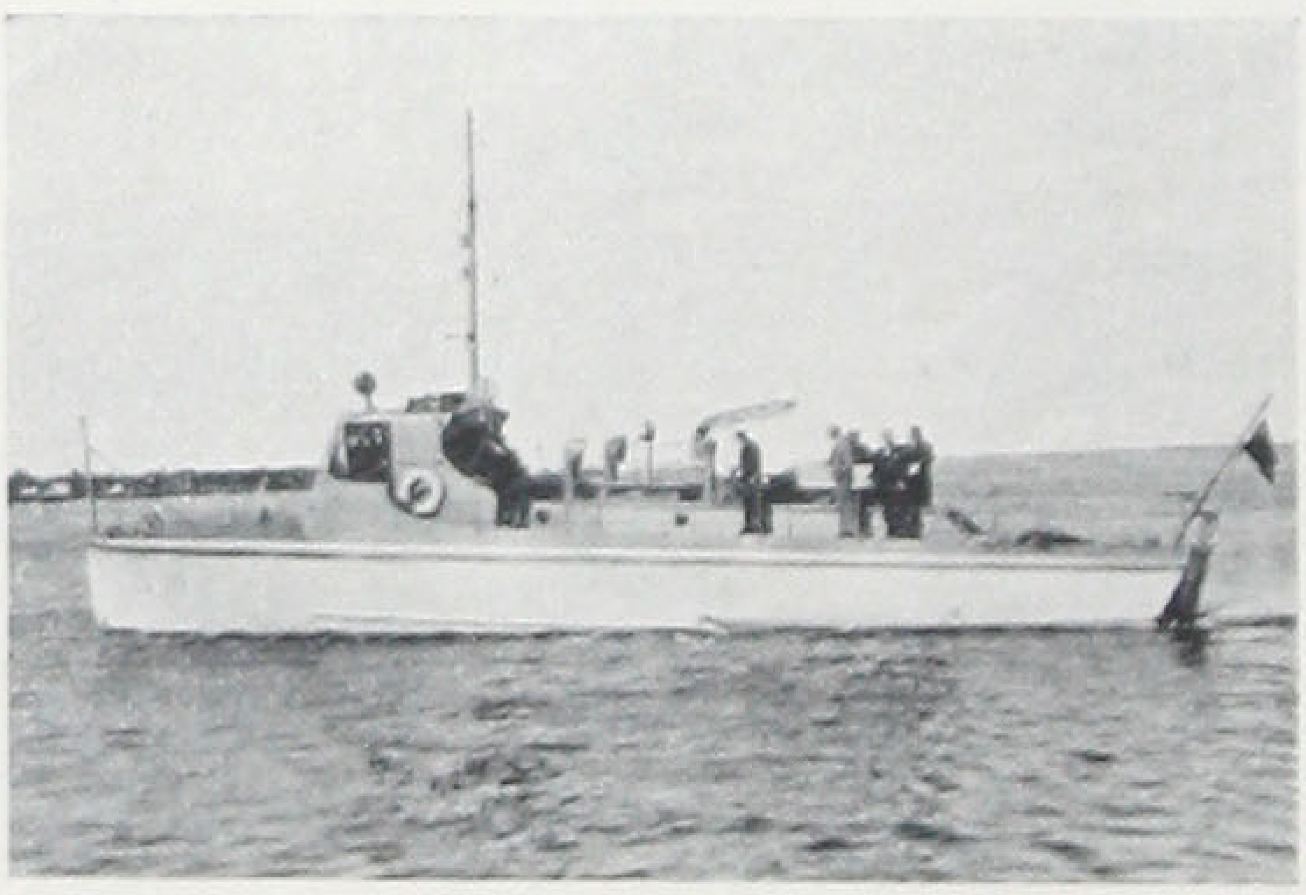
THE WROUGHT ALLOYS of aluminum may be divided into two classes depending upon the manner in which their harder tempers are produced. One class comprises the alloys in which strain-hardening, by definite amounts of cold work following the last annealing operation, produces the varying degrees of strength and hardness. The alloys in the other class depend primarily upon heat-treatment processes to develop their higher mechanical properties.

While there is a wide range of tensile properties in both classes of alloys, the highest combinations of strength and ductility available in the widest range of products are to be found in the heat-treated alloys.

Commercial Forms: Aluminum and its alloys are available in practically all of the forms in which metals are fabricated. The commercial sizes for some of the more commonly-used products are shown in the Appendix, as well as the alloys which are most commonly specified for the various forms. Aluminum Company of America manufactures foil, flat and coiled sheet, and plate; bar, rod and wire; standard structural shapes; moldings and special shapes, both rolled and extruded; seamless drawn tubing in round, square, rectangular, streamline and special shapes; rivets, nails, screws, bolts, nuts, and other screw machine products; collapsible tubes; bus bar, electrical conductor cable and fittings; forgings; and fabricated apparatus, such as chemical equipment, fuel and storage tanks and shipping drums.

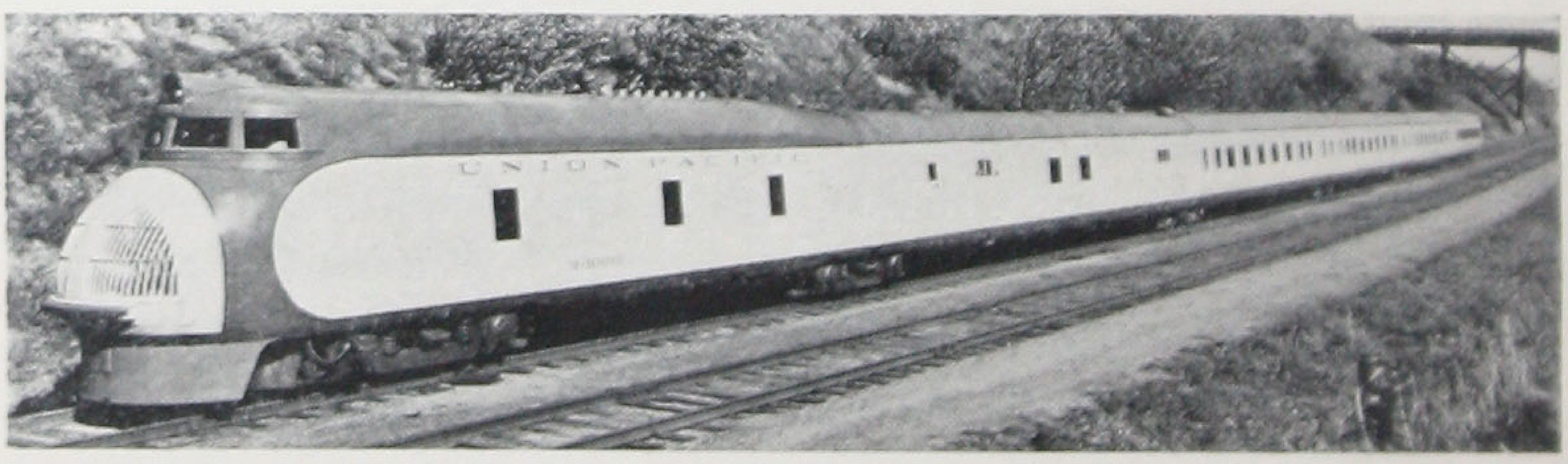


Reducing dead-weight without sacrificing structural strength, non-combustible, shatter- and splinter-proof Alcoa Aluminum is widely used in aircraft construction. For structure, motive power, and accessories.



Special, corrosion-resisting alloys made possible the construction of this fast police patrol boat.

From 8 to 10 tons lighter, Alcoa Aluminum hopper cars resist the corrosion of sulfur compounds.



Because of the availability of economical special shapes, Alcoa Aluminum lent itself unusually well to the construction of this light, but safe, streamlined train.

Reducing the drag of dead-weight wherever mass is in motion, the light, strong alloys of Alcoa Aluminum benefit transportation in all its phases, whether on land, water, or in the air.

Alloy Composition and Nomenclature: The alloys produced by Aluminum Company of America in the various wrought forms are shown in Table 2 (in Appendix, starting on page 55) with their nominal chemical compositions. The alloys are designated by numbers followed by the letter "S" to indicate that they are used in the wrought condition. In some few cases, the number is preceded by a letter to indicate that it is a composition modified somewhat from that of the alloy which is designated by the same number; for example, A17S differs from 17S in that it contains smaller percentages of the same hardening elements.

The symbol which designates the alloy composition is followed by one indicating the temper, but separated from it by a dash; for example, 53S-T, meaning alloy No. 53 in the wrought (S) condition with a temper designated as "T".

Commercially pure aluminum, which contains up to one per cent of impurities and in this sense may be considered as a "natural alloy," is designated by the symbol 2S when in the wrought form.

Temper Designations: In the case of all the alloys, the cast ingot or billet is first worked hot to break down the cast structure. The hot working may be followed by cold working to final dimensions. As the metal is cold worked, it strain-hardens, and it is usually necessary to introduce annealing operations to prevent excessive hardening. In the case of the softer alloys, this may not be necessary except as a means of controlling the amount of cold work necessary to produce the desired temper.

After annealing, the alloy is in its softest and most ductile condition and is said to be in the soft or annealed temper designated by the symbol "O". The hard temper, designated by the symbol "H", is produced by cold working the metal the maximum amount which is commercially practicable for the different alloys.

In one class of alloys (2S, 3S, 4S, 52S), tempers intermediate in the range of tensile strength between the soft and the hard tempers are produced by varying the amount of cold work after annealing. The standard tempers, quarter hard (¼H), half hard (½H) and three-quarter hard (¾H) provide a gradation of properties sufficient for most commercial requirements.

For these alloys, the tempers are defined by the tensile strengths

which result from cold working the alloy. In the soft or annealed temper, the maximum strength is specified to insure that the annealing has been complete. For the harder tempers, the minimum tensile strength is specified with appropriate elongation requirements to define the various tempers.

In the case of the heat-treatable alloys, the symbol "T" is used to indicate that the metal is in the fully heat-treated temper and has the maximum strength developed by heat treatment.

For some of the alloys (17S-T, A17S-T, 24S-T), this temper is obtained by a solution heat treatment followed by natural aging at room temperatures. The solution heat treatment consists in bringing the metal to the appropriate high temperature and quenching from this temperature in cold water. (See page 36 for discussion of practice and theory of this operation.)

Some of the alloys (51S-T, A51S-T, 53S-T) develop their full strength, i.e., their "T" temper, only if the solution heat treatment is followed by a precipitation heat treatment. This consists in artificially aging the alloy at a temperature appreciably higher than ordinary room temperature (U. S. Patent 1,394,534). The symbol "W" may be used only with these alloys to designate the intermediate temper which results if they are not subjected to aging.

This temper is sometimes called the "as quenched" temper, but the name is not strictly accurate as applied to 51S-W and 53S-W, since these alloys undergo some spontaneous aging at room temperatures after they have been quenched. The properties shown for the "W" temper are those which result after the normal aging is practically complete. Immediately after quenching, the tensile and yield strengths are appreciably lower and the metal may be subjected to more difficult forming operations than are possible after it has been allowed to age. The practice of quenching immediately before forming is sometimes used in the case of 17S and 24S, particularly in the case of rivets, in order to take advantage of the better working qualities of the alloy in this condition. The aging then proceeds in the finished assembly.

Strain-hardening may also be used as a means of improving the mechanical properties of the heat-treatable alloys. Relatively small amounts of cold work done on these alloys in the heat-treated temper, "T", produce marked increases in their yield

strengths. The elongation is also quite sensitive to small amounts of strain-hardening, the reduction in this property being greater for small initial reductions in cross-sectional areas by cold work than for subsequent larger reductions. However, by careful control of the amount of cold working, the yield strength may be greatly improved without too great sacrifice in the ductility of the alloy.

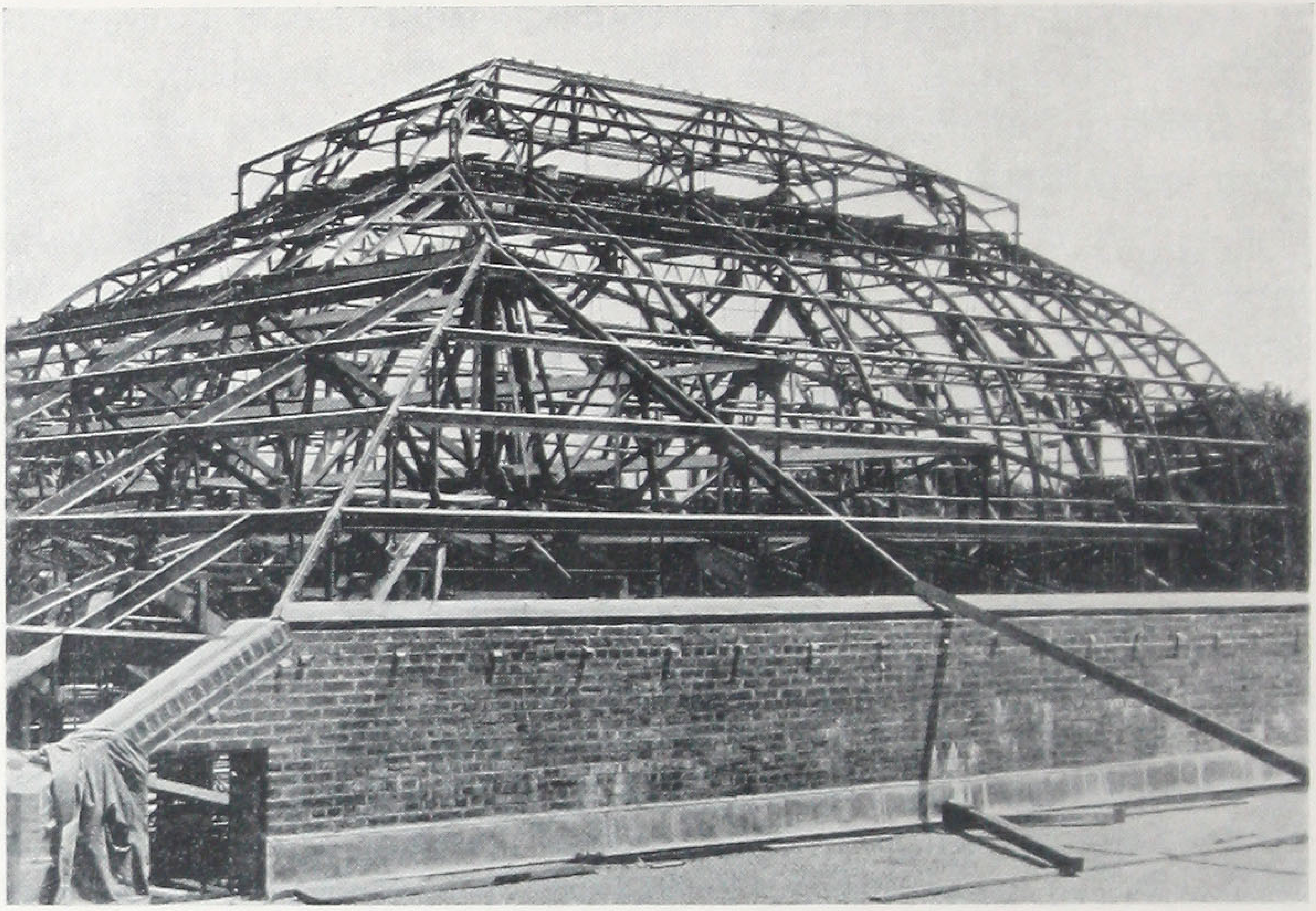
The temper which results from strain-hardening this class of alloys after they have been heat treated is designated by the symbol "RT": for example, 24S-RT. The increase in tensile, shear and bearing strengths is relatively small.

PHYSICAL PROPERTIES

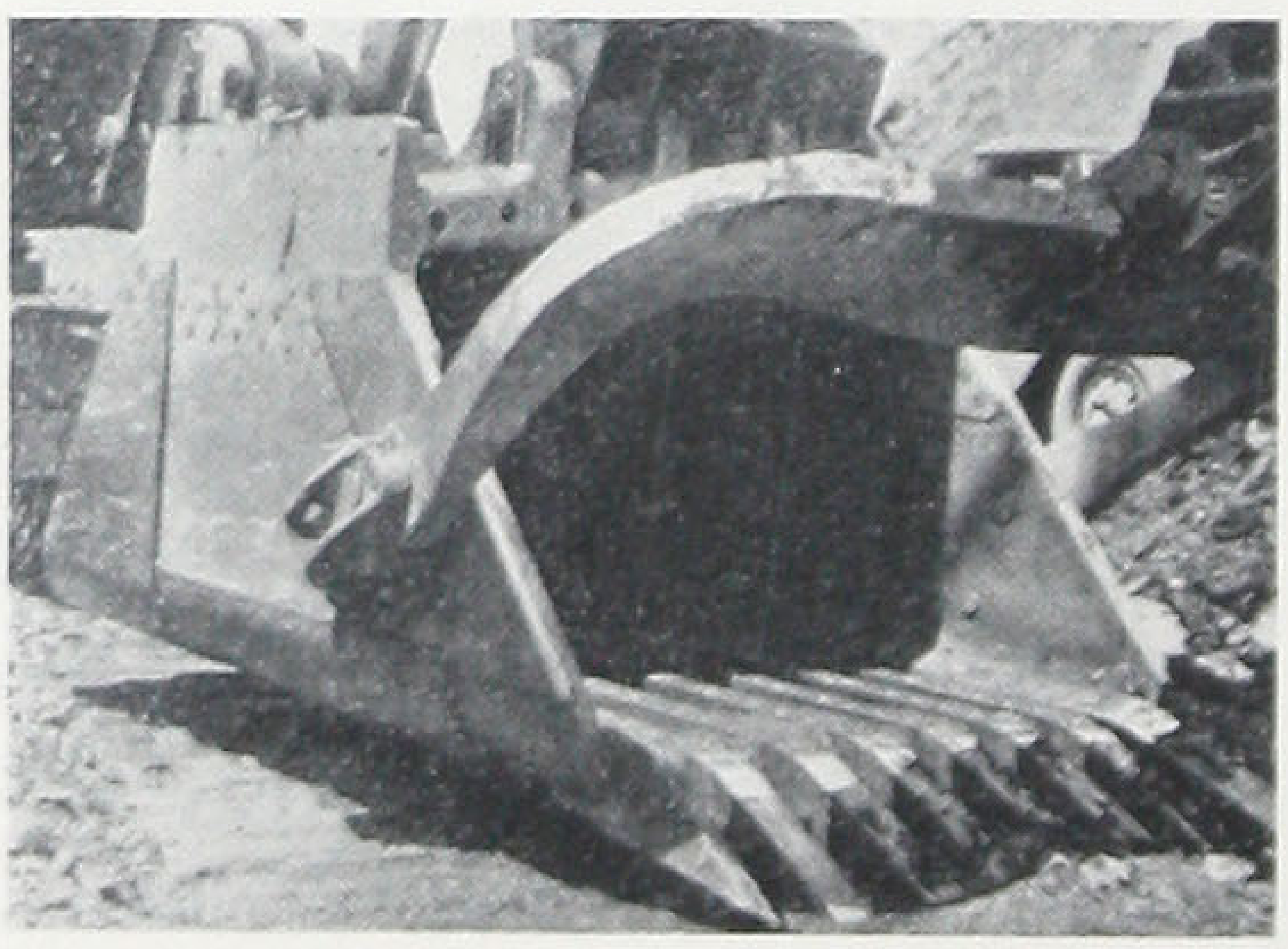
Specific Gravity: The specific gravity of the commercial wrought aluminum alloys differs only slightly from that of the parent metal. The greatest increase in this property, caused by alloying, is about three and one-half per cent, and some of the alloys in which magnesium and silicon, either combined or separately, are the principal hardening elements are actually lighter than pure aluminum. The specific gravities are shown in Table 4, with the weights in pounds per cubic inch. The weights of the casting alloys are shown in Table 11.

Electrical Conductivity: The electrical conductivity of aluminum is lowered by the addition of alloying elements, the reduction varying with the nature of the element and the amount added. Heat treatment and mechanical working also influence this property to a marked degree. In Table 4 will be found the electrical conductivities for the wrought alloys in their various tempers.

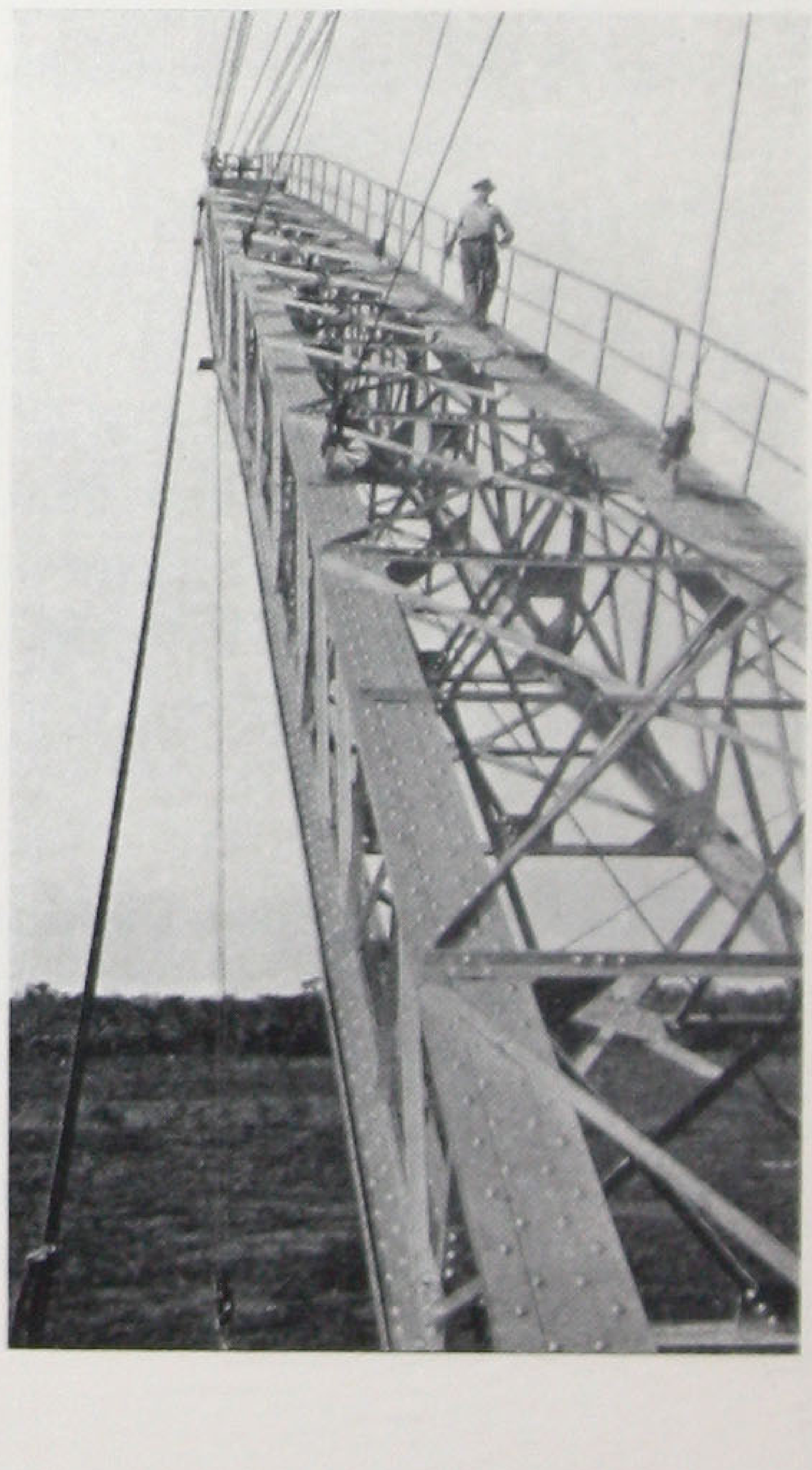
Thermal Conductivity: Aluminum of a purity of 99.6 per cent has a thermal conductivity of 0.52 in c.g.s. units (calories per second, per square centimeter, per centimeter of thickness per degree centigrade), which is equivalent to 1.509 B.t.u. per hour per square foot per inch of thickness per degree Fahrenheit. The thermal conductivities of some of the aluminum alloys are shown in Table 4.



Structural detail showing Alcoa Aluminum sections used in constructing a botanical garden building.



Above—Due to the light weight of this strong aluminum alloy 5-yard dipper, the operating speed for a loading cycle is the same as it formerly was with smaller all-steel dippers, thus increasing the hourly output 43%.



Right—Alcoa Aluminum Alloy No. 17S-T made possible this 175-foot boom, which weighs, fully rigged, 29,000 pounds, or 17,000 pounds less than a standard 150-foot steel boom.

Thermal Expansion: The coefficient of thermal expansion of aluminum is slightly more than twice that of steel and cast iron (See Table 6). The alloys have coefficients the same or slightly less than that of pure aluminum, except those which contain relatively high percentages of silicon in which the value is appreciably lowered. In spite of the difference in expansion when subjected to thermal changes, composite structures in which both steel and aluminum alloys have been used have shown entirely satisfactory performance.

Modulus of Elasticity: Young's modulus, which is the ratio of stress to strain in the elastic range, is approximately the same in aluminum and its commercial alloys. The average value for this constant is approximately 10,300,000 lb. per sq. in. The value may be increased somewhat by relatively large additions of alloying elements. In fact, careful measurements in 24S alloy have given an average close to 10,500,000 lb. per sq. in.

Because of the lower value of this constant as compared with that of steel, it is necessary to use deeper sections in aluminum alloys in order to maintain the same deflection characteristics when they are loaded as beams. Such redesign can be accomplished to produce a structure having the same deflection under load and actually higher ultimate strength than would be obtained with structural steel, and at the same time to realize a saving in weight of more than a pound for each pound of aluminum alloy used.

The lower modulus of elasticity is an asset when impact loads are to be resisted since, other things being equal, the lower the modulus the greater the ability to absorb energy without permanent set. The lower modulus is also advantageous in reducing stresses produced by misalignment, settlement of supports, or other fixed deflections, accidental or intentional.

Mechanical Properties: Typical average mechanical properties of the various wrought alloys are shown in Table 10. These values may be used in comparing the alloys with each other, or with other materials, since typical properties are commonly quoted.

Purchase specifications are based on the minimum values for those properties which are regularly determined in the routine

control of commercial manufacturing operations. Tables showing these minimum properties which can be guaranteed for the various commodities are also included in the Appendix.

It will be observed that the minimum properties guaranteed for an alloy are not the same in all commodities or in all sizes of a given product. Since the type and dimensions of the test specimen specified by standard testing practices vary with the nature of the product or with its dimensions, some of the variations in the guaranteed properties represent differences in the test rather than fundamental differences in the properties of the metal in the various commodities. In the case of rod which is tested in full section, the elongation is measured over a gauge length equal to four times the diameter of the rod in order to compensate for the effect on this property of the variable cross section.

Strain-Hardened Alloys: It has been stated previously that the production of the harder tempers of certain of the aluminum alloys is accomplished by strain-hardening, the different degrees of hardness being obtained by varying the per cent of reduction by cold work after the final annealing operation.

In the manufacture of sheet, tubing and wire, it is standard practice to work the metal cold after the cast ingot has been broken down hot to produce the hot mill slab, the tube bloom or the rod, respectively. In these cases, the amount of reduction can be carefully controlled by proper selection of roll settings or of die and mandrel sizes. The production of intermediate temper involves only the annealing of the stock at the proper size to produce the desired amount of strain-hardening by the cold finishing operations. The only limitation is that the final size shall be enough smaller than the hot mill slab, the tube bloom or the rod to permit the necessary reduction to develop the desired temper.

In the manufacture of extruded products and in the rolling of plate, rod, bar and shapes, the metal is regularly produced from a hot ingot and is reduced to the desired size without intermediate cooling. Where closer tolerances or special surface finish is required, rod and bar may be rolled oversize by an amount sufficient to permit a cold finishing operation. The amount of cold working is chosen from the standpoint of producing the desired

finish and, except in the smaller sizes, does not greatly alter the mechanical properties.

During the process of manufacture of these products, there is some cooling of the metal, the amount of cooling being greater, the thinner the finish size of the material. There is some strain-hardening of the metal, the strength varying from that of the annealed alloy for heavy sections to that of the half or three-quarter hard temper for small sizes of rod or bar. For any given size of product, the manufacturing conditions are fairly uniform, and succeeding lots of material will have substantially similar properties.

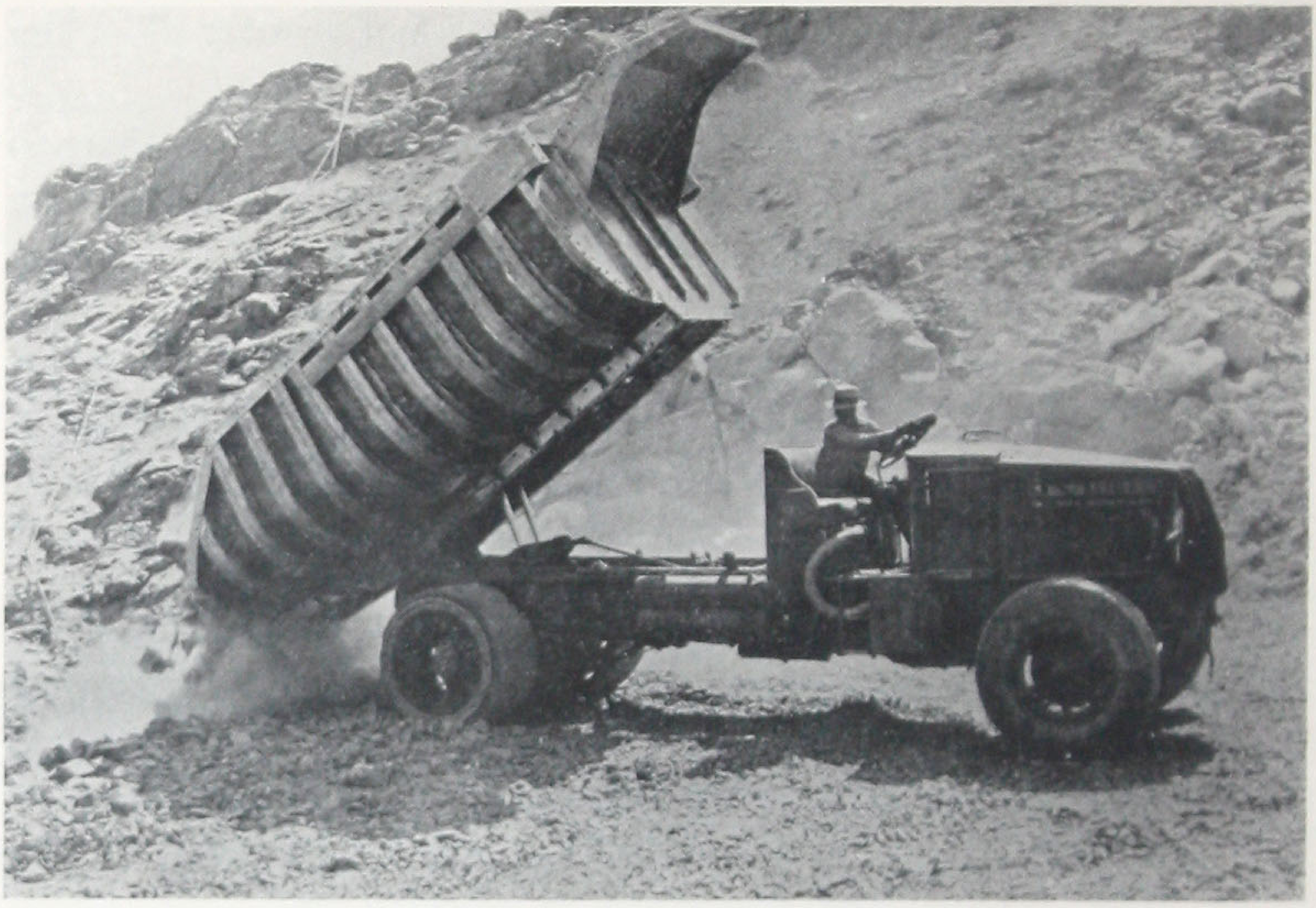
While it is possible in some cases to produce these products in the strain-hardened tempers by adopting special manufacturing methods, it is preferable to obtain the higher strengths by choosing a harder alloy instead of specifying a harder temper, the production of which may entail prohibitive manufacturing costs.

Extruded shapes are produced by forcing the solid metal through a die having an aperture to produce the desired shape. Since the alloys are more plastic at elevated temperatures, these products are produced hot. Depending upon the alloy and the nature of the section, there is some variation in the extrusion conditions and consequently in the mechanical properties of the shapes as extruded. In the case of 2S and 3S, the guaranteed tensile strength of extruded shapes cannot be higher than that of the annealed temper of the alloy, although higher values up to those for the half hard temper are frequently obtained.

Extruded shapes in the heat-treatable alloys are usually heat treated to develop the properties of their heat-treated tempers.

In the Appendix, a table is included showing the approximate tempers of representative sizes of bar, rod, shapes and plate in the various alloys for which these products are supplied "as fabricated" (i.e., as rolled, as cold finished, as extruded) (See Table 39). In general, the ratio of yield strength to ultimate tensile strength is slightly lower in the "as fabricated" products than it is in the corresponding temper produced by cold working.

Choice of Alloy: The choice among the relatively large number of wrought aluminum alloys depends upon the qualities which are required for the particular application. While the mechanical and



One of the world's largest dump bodies, made of the light, strong alloys of Alcoa Aluminum, hauled 25-ton loads up 25% grades at Boulder Dam.

A new aluminum floor system saved 750 tons of dead-weight and added another quarter century to the life of this bridge. It also saved the taxpayers a million and a half dollars.

physical properties are shown in the tables contained in the Appendix, the problem of making the best choice may be facilitated by a brief discussion of the alloys. In order to simplify the form of expression, 2S will be referred to as an "alloy" although it is commercially pure aluminum; it is an alloy only in the sense that it is aluminum containing up to one per cent of other elements as impurities.

Commodities, such as sheet and plate, are available in practically all of the alloys except a few which were developed primarily for the production of forgings, machining rod or for other specific purposes. Experience has shown that the commercial requirements for tubing, rod, bar and structural shapes can be met adequately by a more limited group of alloys and the problems of manufacture as well as the choice by the user are thereby simplified.

The alloys 2S, 3S, 4S and 52S comprise the group in which the harder tempers are produced by strain-hardening. They are listed in the order of increasing tensile strength for a given temper. For applications in which ease of forming by drawing, spinning or stamping is of paramount importance, and the requirements of the service which the part must perform do not impose the requirement of high strength, 2S or 3S is commonly specified. Because of their greater ease of manufacture, these alloys offer the advantage of lower cost. In any given temper, 3S is slightly more difficult to form than 2S. The choice of alloy and of temper will depend upon the severity of the forming operations. For some uses, the greater strength and stiffness of 3S make its choice desirable in spite of the slightly greater fabricating difficulties. Both 2S and 3S sheet are used in the manufacture of drawn cooking utensils, bottle and jar closures, cosmetic containers, and a variety of similar articles. Depending upon the depth of the draw, the temper of the sheet may vary from soft to three-quarter hard; the half hard temper is frequently specified. The final choice must be based on the trial of samples on the tools which are to be used in commercial production.

The alloys 4S (U. S. Patent 1,797,851) and 52S are much stronger than 3S. In the quarter hard temper (4S-¼H, 52S-¼H), their mechanical properties are appreciably higher than those of 3S in the hard temper (3S-H). Although 52S has a higher tensile

strength than 4S, its yield strength is somewhat less in the strain-hardened tempers, and its forming qualities are decidedly better than those of the latter alloy. This fact, together with its excellent resistance to corrosion and its high endurance limit, has caused the demand for this newest of the aluminum alloys to exceed that for many of the older alloys.

In their harder tempers, both 4S and 52S have yield strengths comparable with that of 17S-T, the most widely used of the heat-treatable alloys, although their tensile strength and elongation are not so high. In the form of plate, rod and bar, which are not regularly produced in the strain-hardened tempers, these alloys make available mechanical properties intermediate between those of 3S and those of the stronger heat-treated alloys.

Heat-Treatable Alloys: The heat-treatable alloys present a wide range of properties to meet the varied requirements of the structural applications of aluminum products. The oldest and most generally used is 17S. It is manufactured in practically all of the forms in which metals are fabricated. A modification of this alloy containing lower percentages of the alloying elements, A17S, was developed to provide a material which would withstand more severe forming in the heat-treated temper than is possible with 17S. The mechanical properties are lower, but it finds some use where the higher strength is not required.

The alloy 51S in its fully heat-treated temper (51S-T) (U. S. Patent 1,472,739) has a yield strength higher than that of 17S-T, but its tensile strength and elongation are appreciably lower. In this temper, it is capable of only limited forming, but it is readily workable in the quenched temper (51S-W). Difficult forming operations may be performed on the alloy in the quenched temper (51S-W) after which the part may be aged at elevated temperatures to develop the higher strength of 51S-T. Because of its greater ease of fabrication, it is sold at a price lower than that of 17S and for many purposes its properties are adequate.

The alloy 24S makes available a material having even higher mechanical properties than those of 17S. The tensile and yield strengths of 24S-T are approximately 8,000 lb. per sq. in. higher than those of 17S-T; in the case of the yield strength this represents an increase of approximately 25 per cent. This is of par-

ticular interest since it makes possible the use of Alclad 24S sheet (See page 31), with higher design factors than are possible with the use of bare 17S sheet. This alloy is finding increased use in aircraft construction and in other structures where the maximum strength combined with the minimum weight is required. Strain-hardened after heat treatment, this alloy (24S-RT) has the highest strength of any of the commercial wrought aluminum alloys.

For architectural use, an alloy was desired having the maximum resistance to the corrosive action of the atmosphere from the standpoint of retaining both its mechanical properties and its surface finish. The alloy should have good forming qualities and should have tensile and yield strengths superior to those of 3S alloy in the form of extruded or rolled sections. To meet these requirements, the alloy 53S (U. S. Patent 1,911,077) was developed. In a short time the use of the alloy extended beyond the application for which it was originally developed because of its excellent general qualities. For maximum resistance to corrosion (comparable with that of 2S) either 53S or, in the case of sheet, 52S, is recommended where their mechanical properties are adequate. Where higher strengths are required, together with maximum resistance to severely corrosive conditions, Alclad 17S and Alclad 24S are available in the form of sheet, plate and wire.

Alloy 11S has been developed to provide a material having properties comparable with those of 17S-T, but with free-cutting machining qualities to make it more suitable for use in high-speed automatic screw machines. Experience in a number of plants has demonstrated that in 11S-T3 this result has been fully realized. Its yield strength is about one-third higher, although its ultimate strength is somewhat lower than that of 17S-T. In addition to its use for machining rod, 11S is also available in the form of forgings.

Forgings: The alloy most extensively used in the manufacture of forgings is 25S (U. S. Patent 1,472,738). This alloy in its fully heat-treated temper (25S-T) has mechanical properties very nearly the same as those of 17S-T. It is more easily worked at elevated temperatures, however, and for this reason, it is generally used for forged parts. For some forgings, 17S-T is specified be-

cause of its greater resistance to severely corrosive conditions. Forgings of 14S-T (U. S. Patent 1,472,740) alloy have highest mechanical properties of any of the alloys which are produced in this form, as may be seen by reference to Table 19. It has good resistance to corrosion and can be forged at least as readily as 17S. The alloy A51S can be forged even more easily than 25S and is therefore used for large and intricate parts which cannot be produced in the harder alloys. Because of its lower cost, it is also used for forgings in which higher mechanical properties are not required.

For certain applications, notably in the rayon, dairy and brewing industries, unusually severe corrosive conditions may determine the choice of 53S-T forgings.

The case of machining of 11S-T makes it best suited for certain purposes.

The alloy 70S (U. S. Patent 1,924,729) is likewise used where a lower cost product is desired. For forged parts, such as pistons, in which the retention of strength at elevated temperature is essential, the alloys 32S (U. S. Patent 1,799,837) and 18S are used. In addition to good mechanical properties at the working temperatures of internal combustion engines, 32S has the advantage of a lower coefficient of thermal expansion than that of other wrought aluminum alloys.

Extruded Sections: The extrusion process makes possible the production of shapes which have been designed to facilitate the erection of the structure in which they are used, and in which the metal is disposed more efficiently with relation to the stresses which it must withstand than is possible in standard rolled structural shapes. The use of such extruded sections has greatly simplified aircraft design and has contributed largely to the economic success of lightweight railway car construction. The savings in erection cost resulting from the use of special extruded shapes has gone far in offsetting the higher cost of aluminum alloys as compared with structural steel. These shapes also have made possible even greater saving in weight than could be accomplished by the substitution of standard rolled structural shapes of aluminum alloy for similar sections in structural steel.

Forming: Commercially pure aluminum, 2S, is outstanding for the ease with which it can be drawn, spun, stamped or forged. Starting with the metal in its annealed temper, articles requiring several successive drawing and spinning operations may be made without the necessity of any intermediate annealing. Since the alloys are less ductile than the pure metal, they require more liberal radii for bends and are capable of withstanding less severe forming. However, there is a considerable range of fabricating qualities among the various alloys in their different tempers, from 3S-O, which is only slightly less ductile than 2S-O, to 51S-T, which is not used where appreciable amounts of forming are required.

The alloys 2S, 3S, 4S and 52S cover a wide range of mechanical properties in their various tempers. Since their harder tempers are obtained by cold working during the process of manufacture, the amount of forming which can be done on them is greater, the softer the temper. For many drawing operations, the half hard temper retains sufficient ductility for good working qualities even in 4S and 52S, and some less severe draws are successfully accomplished with these alloys in the hard temper.

Aluminum alloys are frequently fabricated on tools designed for use with other metals. There are, however, some differences in fabricating practices, a knowledge of which may be helpful in more difficult forming jobs. In drawing or stamping operations, successful results may depend upon the choice of the proper lubricant. The light lubricating oils, marketed under the designation "metal oil," are most commonly used in large scale operations. The best lubricant is tallow, mixed with a small amount of mineral oil, but because of its greater cost and the greater difficulty of applying it to the blank and removing it from the finished work, it is used only on more difficult operations for which metal oil does not prove successful.

The surface finish of the tool also exerts considerable influence on the results. Tool steel with polished surfaces may be required for more difficult draws of the harder alloys, while for many jobs, cast steel or even cast iron tools are satisfactory, provided the number of parts which are to be made is not too great.

In forming aluminum alloys, it is necessary to recognize their characteristic properties. The chief requirement for successful

working is that the tools shall permit a suitable radius for bending and drawing operations. The radius which is required varies both with the grade of the alloy and with the thickness of the material. The radius of a bend will also depend to some extent on the type of bending equipment which is used. Frequently, a small change in the tools has been found sufficient to obviate the necessity of choosing a softer temper or type of alloy. In some cases, this change consisted only in the slight rounding of a sharp edge or merely a polishing operation to improve the surface so as to prevent the metal from flowing into scratches or flaws in the tools, which action would cause the metal to tear. In certain difficult forming operations, it may be necessary to resort to several successive draws with intermediate annealing, starting, of course, with annealed material.

Table 5 is intended as a guide in the choice of a suitable material or of a proper forming radius, not as a tabulation of definite operating limits. The final choice of the alloy or of the working radius should be based on a trial under the conditions to be used in production. The relative ease of forming is also affected by the nature of the forming process. While experience in handling these alloys makes possible some prediction as to the material which may be used, the final answer must be obtained by actual trial of different materials on the tools.

Hot Forming: By raising the heat-treatable alloys to suitable temperatures, it is possible to form them around much smaller radii than are possible at ordinary temperatures. By working at a temperature around 400°F., there is considerable improvement in their forming characteristics. Provided the metal is not held at this temperature for too long a time, preferably not more than a half hour, there is no appreciable loss in mechanical properties. This method of forming is especially suitable for 51S-T and 53S-T since their resistance to corrosion is not impaired by the heating, as is the case with 17S-T and 24S-T (See page 29). Even with these latter alloys the effect may not be serious, since hot forming will be used only on heavy sections.

Heat-treatable alloy plate can be formed into angles and other shapes by heating the metal and forming it in dies. For some classes of material, the best working temperature is in the heat-

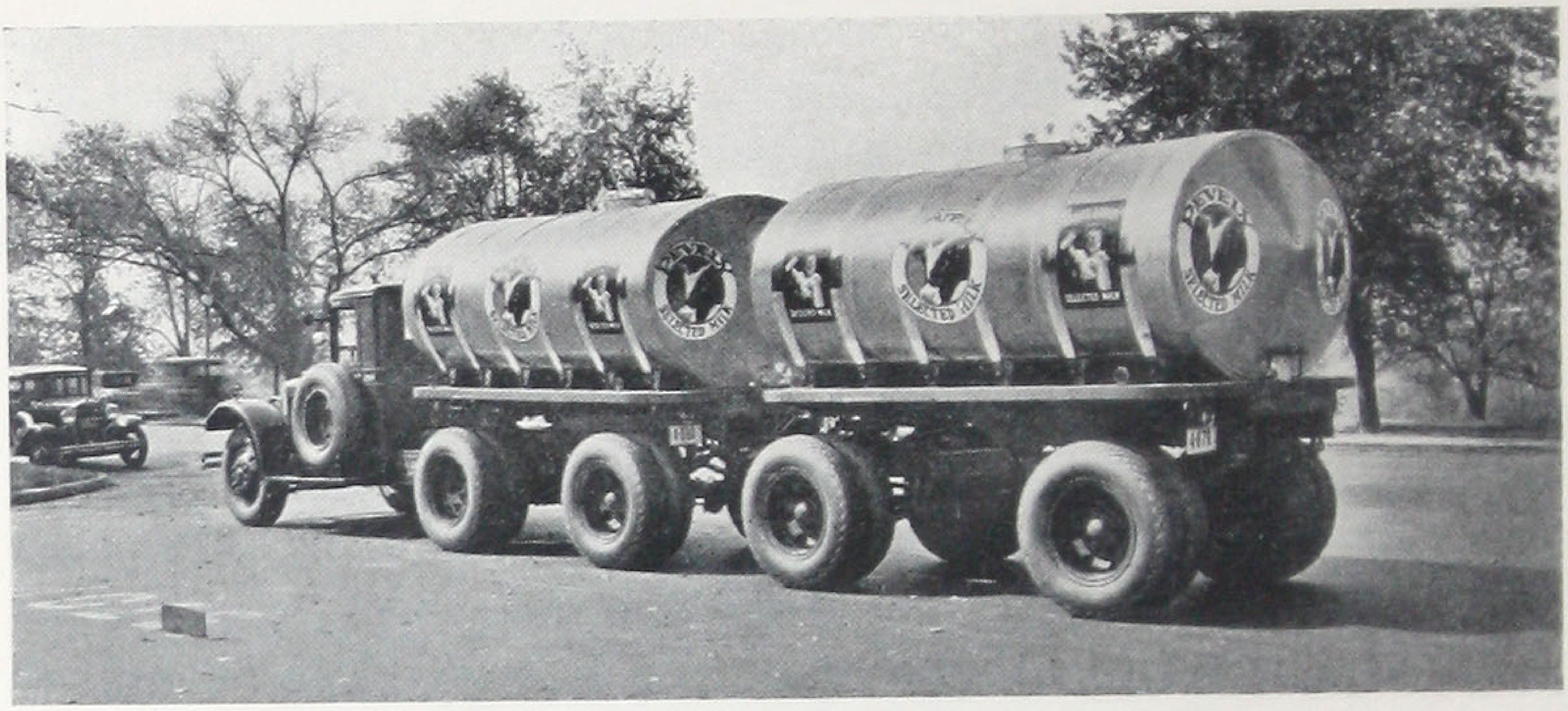
treatment range. In these cases, the chilling of the metal in the steel dies may constitute a satisfactory quench (U. S. Patent 1,751,500), such that the mechanical properties of the heat-treated temper will be developed in the finished part after a suitable aging. In some cases, the metal must be formed at a temperature lower than that required for heat treatment. The advantage of quenching in the dies to avoid warping may be obtained by reheating the formed section to the heat-treating temperature and replacing it in the dies instead of quenching in water. Natural aging or precipitation heat treatment, as may be appropriate for the alloy, will then develop the full properties of the metal. It must be emphasized that die quenching can be relied upon to give satisfactory results only in case the die is of such a character that there is intimate contact with the metal which is being formed. The dies must also be of sufficient size to have adequate heat capacity to absorb the heat from the alloy and bring it promptly to room temperature.

Welding: The wrought aluminum alloys are joined by welding as a common commercial practice. Torch, arc, or resistance welding are applied as the parts may require. The technique of welding aluminum differs from that used on steel, but is readily mastered with a little practice.

Because of the oxide film which forms on an exposed surface it is necessary to use a flux in torch or arc welding aluminum. For arc welding, a flux-coated rod is used to advantage. When welding the common alloys by either of these processes, a welding rod of 2S or of the same composition as the alloy which is being welded is often used, although an aluminum alloy rod containing five per cent of silicon is more easily handled and gives better results in complicated welds. This latter rod is recommended for most applications in the welding of the heat-treatable alloys.

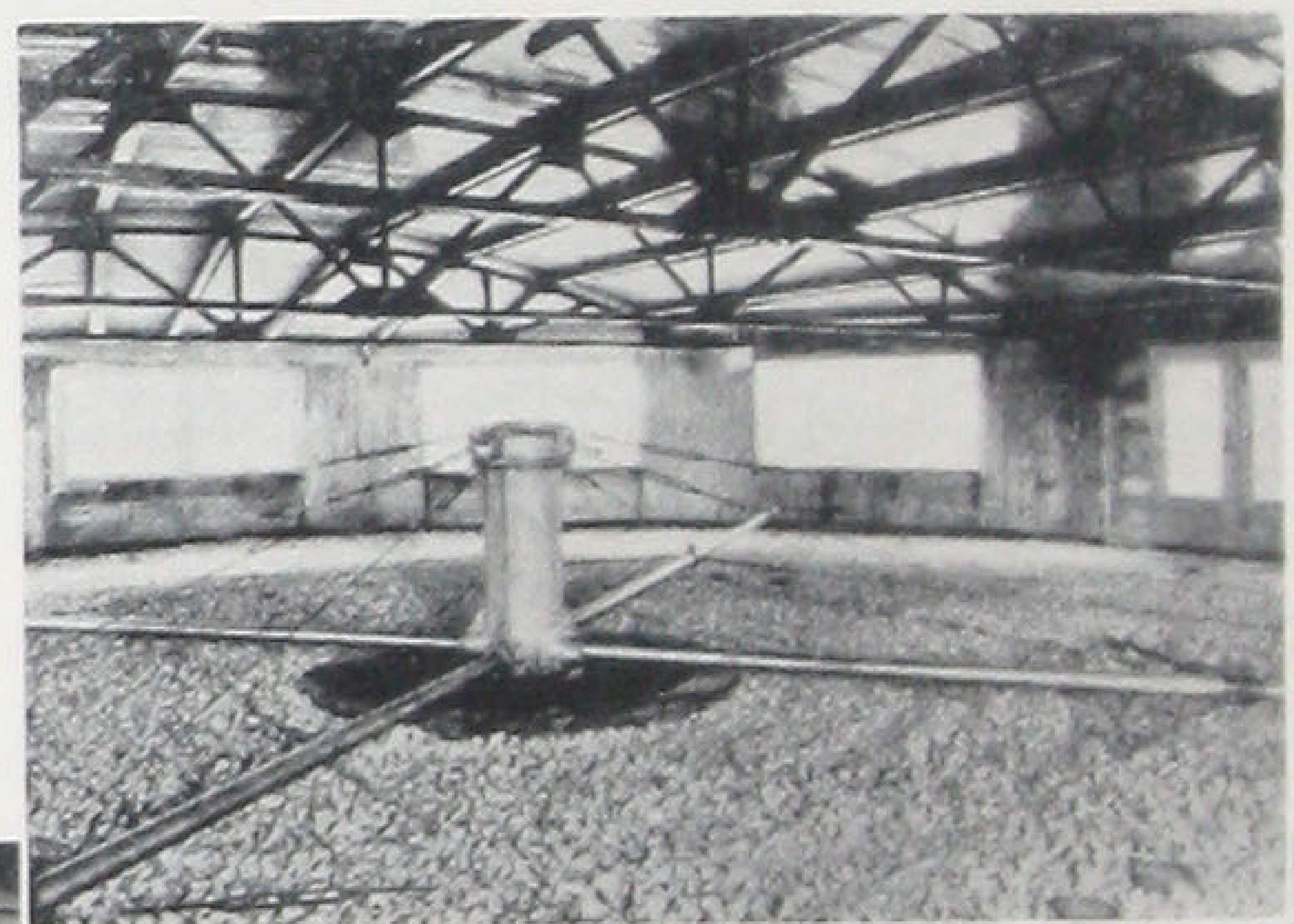
Butt, lap and fillet joints are made by torch welding, using either the oxy-hydrogen or the oxy-acetylene flame, with comparable facility to similar joints in steel.

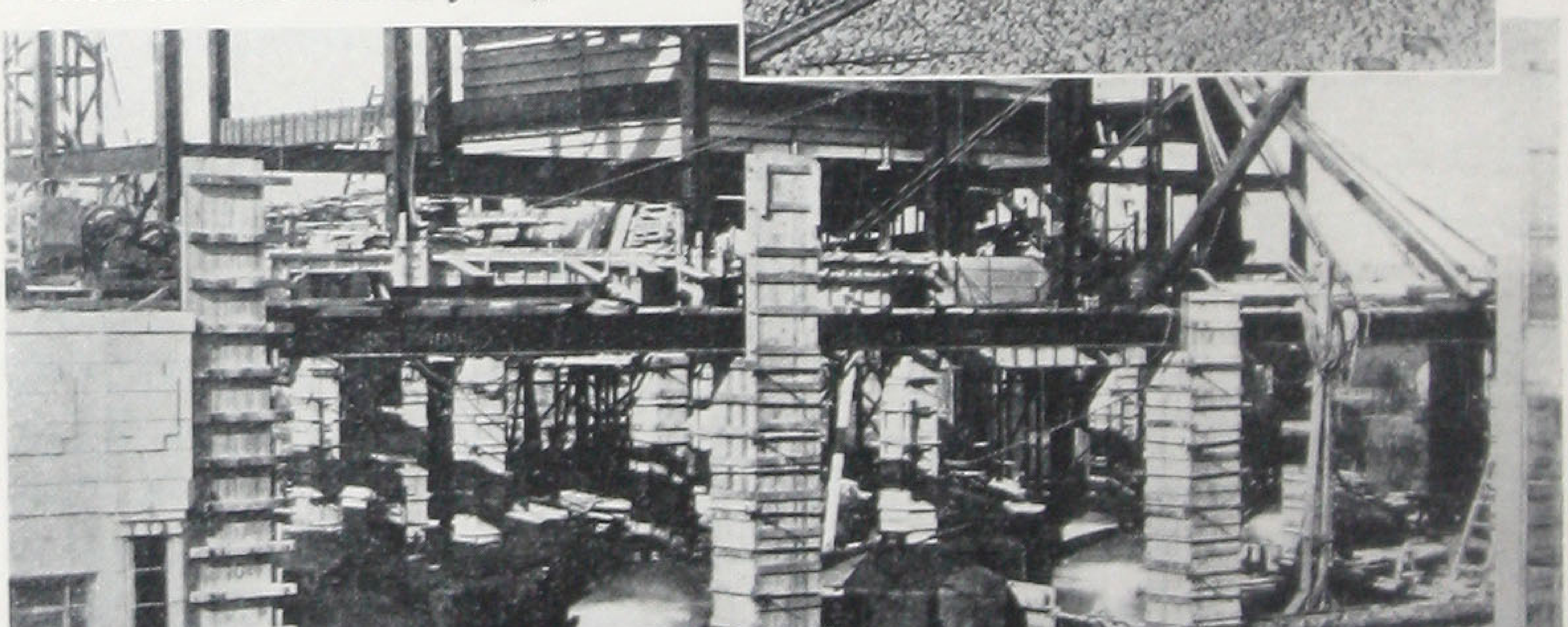
There are some limitations to the applications of arc welding. However, butt joints are readily made on material thicker than about 1/16 inch. This process possesses the advantages of greater speed and of less distortion of the part as compared with torch



Above—These 2300-gallon aluminum milk transport tanks enable the operator to carry 200 gallons more. An application of aluminum in the Dairy Industry.

Right — All-aluminum rotary distributor for applying sewage liquid to circular trickling filter beds. The corrosion resistance of aluminum interests the sanitary engineer.





Each of these thirty-nine beer tanks is tall enough to span three floors of a modern brewery and big enough to house your automobile. Unaffected by beer, aluminum guards its goodness.

Alcoa Aluminum is non-contaminating, non-toxic, forever sterile. The facility of fabricating aluminum—handling, forming, welding, riveting, finishing—is demonstrated by the many large-scale applications. The alloys of Alcoa Aluminum are strong, yet light.

welding; also, the effect on the structure and temper of the parent metal extends a smaller distance from the joint.

Some general considerations should be taken into account in designing parts containing welded joints. The strain-hardened alloys after welding are annealed for a short distance from the weld. Consequently, the design stresses for annealed alloy should be applied. The metal in the weld has a cast structure having about the same strength as the annealed metal, but less ductility. If the weld head is left as welded, the joint is usually stronger than the adjacent metal. Grinding of the welds will reduce the strength of the joint somewhat; but hammering them will generally accomplish the same purpose as grinding, without the sacrifice in strength.

Welding the heat-treated alloys tends to destroy the effects of prior heat treatment. The annealing temperature range is exceeded in the metal adjacent to the weld and the rate of cooling in the air is fairly rapid, consequently, its strength is usually intermediate between that of the fully-annealed alloy and that which would result from the solution heat treatment. Except in the case of 53S, the change in the temper of the metal resulting from the heating also has an adverse effect upon its resistance to corrosion. The loss in these properties can be partially recovered by reheat treatment or by performing the welding operations before heat treatment where this plan is feasible. Where the joint is depended upon for maximum efficiency, torch welding, and, in many cases arc welding, cannot be considered equal to a well-designed mechanical type of joint.

Resistance Welding: Resistance welding, embracing spot, seam, and butt welding, may be employed in the fabrication of aluminum in a manner similar to that used for other materials. Due to the entirely different physical characteristics of aluminum, the technique and equipment employed will differ considerably from that used for steel. In some cases, however, equipment used for steel may be modified or added to in order to provide excellent results when used with aluminum or its alloys.

In addition to the required changes in equipment, several times the electrical capacity is required for aluminum as compared with a similar resistance weld application in steel.

Liquid or gas-tight tanks may be conveniently fabricated by means of seam welding, the weld in effect consisting of a succession of spot welds so closely spaced as to overlap and provide a continuous seam. The operation is entirely automatic and commercially practicable.

Spot welding may in many cases be used to replace rivets with decreased cost and an improved mechanical result.

RESISTANCE TO CORROSION

The resistance of a material to corrosion is a relative term and depends upon a comparison with other metals or with other alloys of the same metal. None of the commercial metals is immune to all conditions to which structural materials are exposed. There is always the possibility of overstressing the dangers of corrosion with the result that the prospective user is deterred from employing the metal where there is no occasion for concern. On the other hand, if the possibility of trouble is ignored, metal failures may result, which could have been avoided by simple protective measures.

Commercial aluminum contains, as a maximum, one per cent of impurities. This metal, designated 2S when in the wrought condition, is widely used because of its high resistance to ordinary conditions of exposure. Selected grades of higher purity are even more resistant to most forms of attack. The addition of other elements to produce alloys from commercial aluminum does not improve the resistance of the metal and in most cases causes some loss in this property. Magnesium, manganese, and chromium have no adverse effect and silicon has but little.

All of the commercial aluminum alloys are properly classed as materials resistant to corrosion, although some are more resistant than others and, hence, are chosen for those applications in which this property is of major importance.

The alloys 3S and 4S behave practically the same as 2S under similar conditions of exposure. The alloy 52S appears to be more resistant to attack than 2S, both from the standpoint of the retention of its mechanical properties and of its surface appearance.

Considerable study has been made on the effect of the temper of these alloys on their resistance to attack. In general, it may

be stated that any differences in this property as a result of strain-hardening are less than the small differences which are normally to be expected from one lot to another of commercial materials.

These alloys are generally used without any protection other than the usual precaution to avoid electrolytic action from contact with a dissimilar metal. Under severe conditions of exposure, such as may prevail on shipboard or where the metal is in contact with wood or other absorbent material continually in the presence of moisture, a protective coat of paint is desirable as an added precaution.

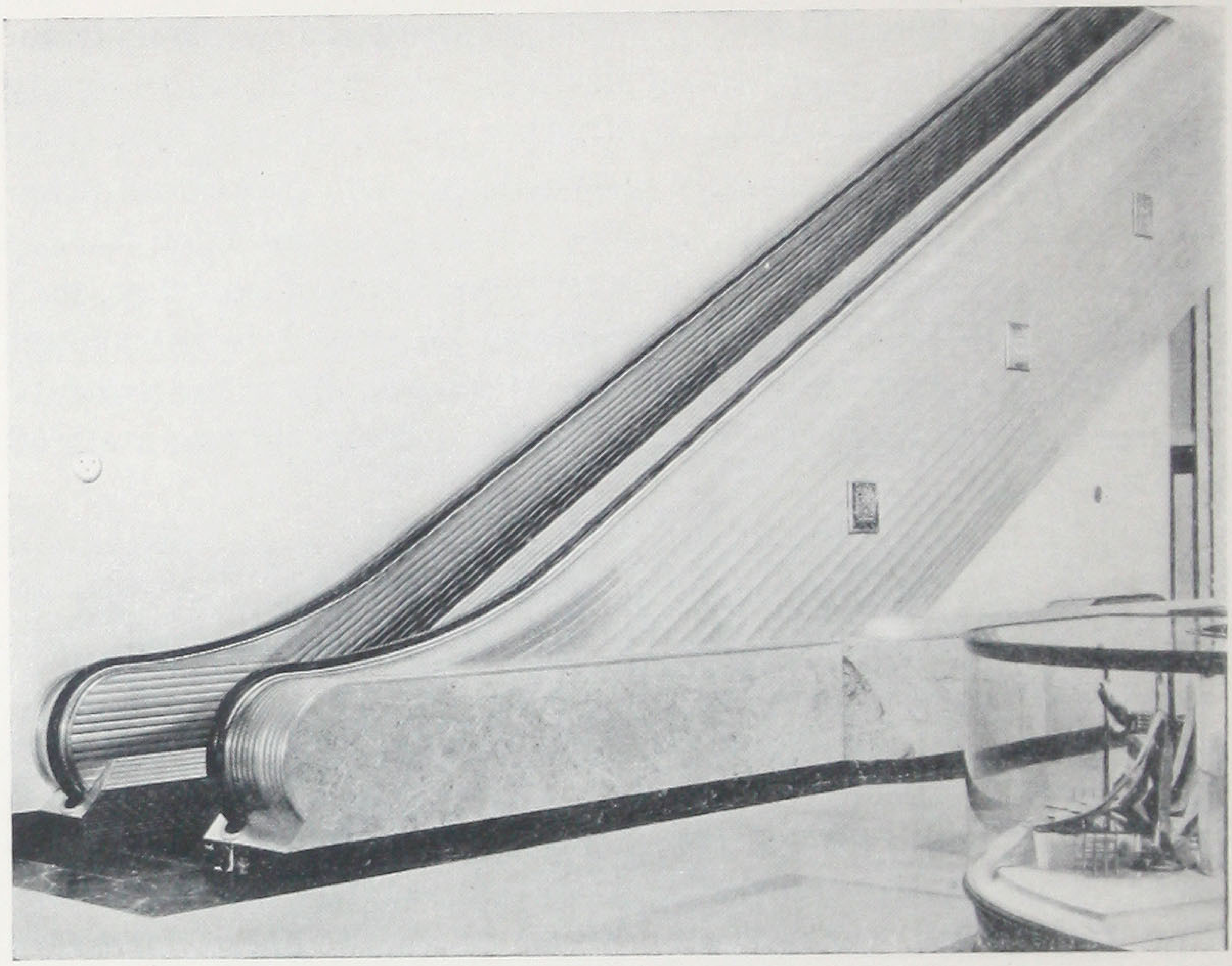
Among the heat-treatable alloys, 53S is the most resistant to corrosion, it being fully equal to 2S in this respect. The other alloys in the group, while resistant to attack, are commonly protected when used in exposed locations.

In general the heat-treatable alloys are in their most resistant state when they have been subjected to solution heat treatment followed by aging at ordinary temperatures. In the case of 53S alloy, heating after quenching to develop the maximum properties of the alloy (precipitation heat treatment) has so slight an effect, that for all practical purposes the alloy may be considered equally resistant in all its tempers (53S-O, 53S-W and 53S-T).

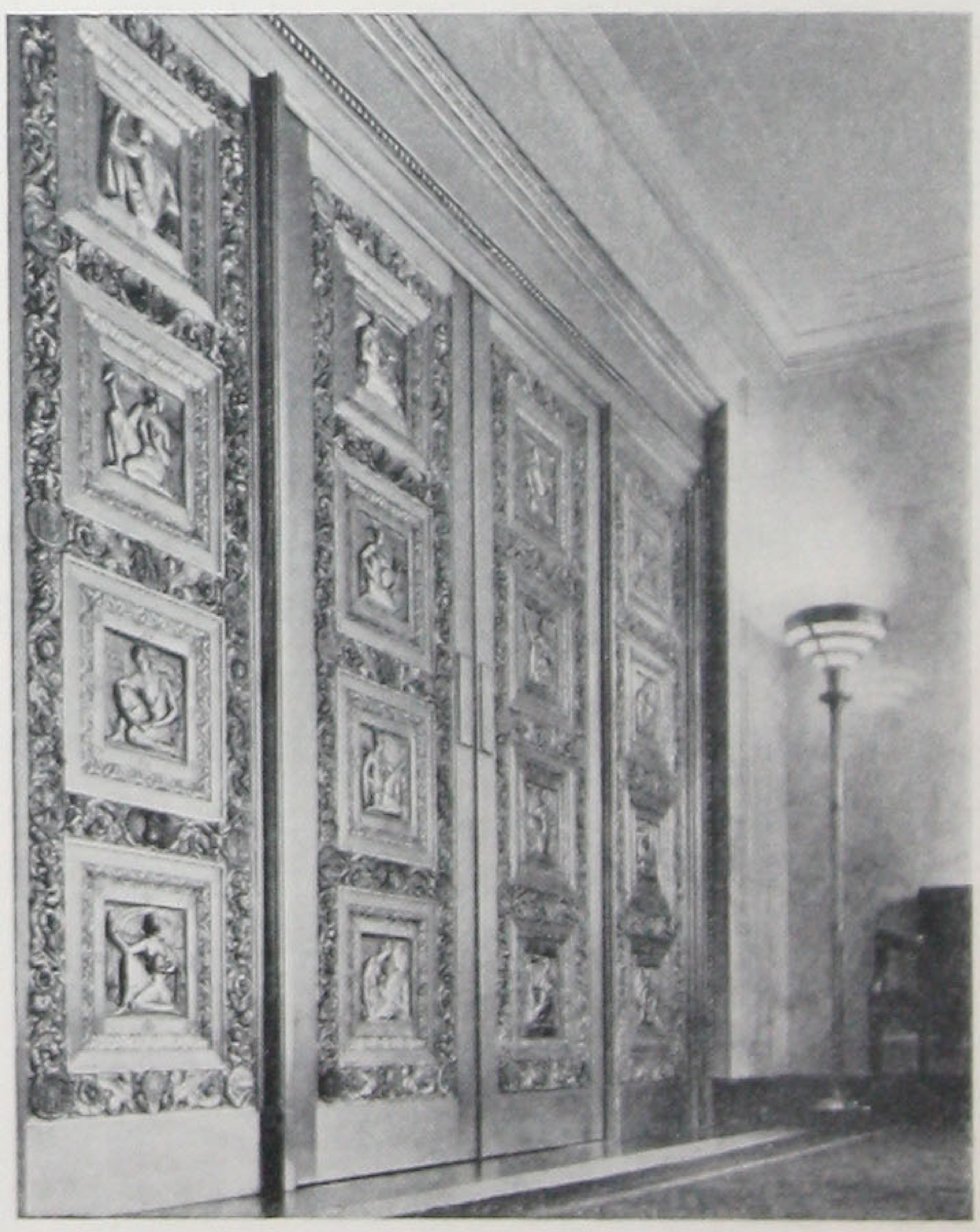
Alloy 51S-W is somewhat more resistant than 51S-T, precipitation heat treatment being necessary to produce the latter temper. There is little difference in the resistance of 17S-T and 24S-T; 51S-T compares favorably with these materials. Heating 17S-T, A17S-T and 24S-T after they have been quenched impairs their resistance to attack. Baked enamel finishes have been proposed for the protection of these alloys, but other protective treatments have been developed which do not require heating and, hence, do not have the disadvantage of decreasing the inherent resistance of the metal.

Alloys 51S-T and 53S-T may be heated at temperatures up to 400°F. for as long as one-half hour without appreciable loss in either mechanical properties or resistance to corrosion. This is an advantage when it is necessary to form them more severely than can be done at ordinary temperatures, or when it is necessary to use hot-driven rivets in joining them.

While experience shows that aluminum alloys are corrosion-resistant materials and, in many of their applications, they are



Above — Fabrication technique was an important factor in this installation of new escalators. Easy to form, Alcoa Aluminum welds beautifully, assembles economically. Non-rusting in the moisture-laden atmosphere, these escalator facings are treated by the Alumilite Process. They will not smudge, stain nor tarnish.



Right — Aluminum doors representative of intricate and elaborate design are readily cast in aluminum. Other qualities that recommend aluminum for architectural ornamentation are lightweight, strength, resistance to corrosion, and easy workability.

used without any protective coating, under severe corrosive conditions, protection may be desirable.

The efficacy of protective paints on aluminum alloys depends mainly upon the composition of the paint, upon the preparation of the aluminum surface before painting, and upon the inherent resistance of the alloy. For service under ordinary atmospheric conditions, it is usually sufficient to clean the dirt and grease from the surface with a chemical cleanser which cleans with only superficial attack of the aluminum surface. Using a solvent is less desirable but may give satisfactory results. For service conditions where the part is to be kept wet or subjected to high humidity for extended periods, as, for example, in seaplanes, anodic coating of the aluminum surface is advantageous in promoting the adhesion of the paint, and in increasing the protection of the aluminum alloy.

Aluminum paint, made by mixing aluminum bronze powder or paste with a suitable synthetic resin varnish vehicle, affords excellent protection. The use of a priming coat containing zinc chromate may be advantageous for service under conditions of severe exposure. Where the metal is continually subjected to moisture, as on the inside of pontoons or seaplane floats, bituminous paints have given good service. The bituminous paint may be covered to advantage by a coat of aluminum paint.

Alclad Products: "Alclad" is the registered trade-mark used by Aluminum Company of America to identify alloy products of exceptional resistance to corrosion in which this property is imparted by means of a surface layer of aluminum of high purity or a special aluminum alloy, alloyed and integral with the core. The thickness of the surface metal is so chosen as to retain, in the resultant product, the maximum physical properties consistent with adequate protection of the alloy core. In the commonly-used thicknesses of Alclad 17S-T and Alclad 24S-T sheet, the tensile and yield strengths are approximately ten per cent lower than the values for the uncoated alloys.

It is noteworthy that the coating not only protects the alloy which it covers, but by electrolytic action, prevents attack on the sheared edges of the sheet or other sections of the base alloy which may be exposed by scratches or abrasions. Ordinary 17S

alloy rivets, used to join Alclad sheet, are likewise afforded considerable protection because of this electrolytic effect. Such protection is accomplished at the expense of some solution of the metal surface layers. Under continued exposure to sea water, corrosion products may accumulate on the surface of the sheet as a result of this action. While the appearance of the metal may be impaired, mechanical test specimens taken from the sheet show that the base metal has not suffered loss of mechanical properties. With proper cleaning the appearance of the surface can be restored without removing the surface metal upon which the protection depends.

Test specimens of Alclad sheet, subjected to the standard salt spray test for a period of five years, have shown no loss in mechanical properties. Except for some solution of the pure metal layer near the machined edges and in a few isolated spots, the sheet appeared bright. A riveted tensile test specimen in which ordinary 17S-T rivets were used to join the Alclad sheets, had the same strength after three years' exposure to three and one-half per cent sea salt spray, as the control specimen which had been carefully stored.

In certain cases where resistance to surface abrasion must be considered, as in the case of wire, the surface layer may be an alloy which is harder than the pure aluminum, but which has excellent resistance to corrosion; it is also anodic to the underlying strong alloy, and therefore renders electrolytic protection in the same manner as the pure aluminum surface.

Sheet and plate are available in Alclad 17S and Alclad 24S in all the tempers in which the base alloy is supplied. Alclad 17S wire is manufactured with the corrosion-resistant, hard, alloy-surface. Other Alclad products are in process of development.

Alclad sheet is extensively used in the aircraft industry. The metal-clad dirigible airship, ZMC-2, made for the United States Navy, has Alclad 17S-T sheet for the outer shell. Although only 0.0095 of an inch in thickness, and unprotected, test samples from this shell showed no deterioration after five years of service. Some of the leading manufacturers use Alclad sheet in various parts of their planes. For most types of service, it is not necessary to paint Alclad sheet; but for seaplane floats and other applications where corrosion conditions are unusually severe, a protective coating

of paint may be found necessary. The surface of Alclad sheet may be anodically treated, prior to painting, in order to obtain the maximum adherence of the paint.

The use of Alclad sheet to replace the plain sheet of the same alloy sometimes requires the use of slightly heavier gauges to compensate for its lower tensile properties. This increased metal thickness does not necessarily represent a corresponding increase in weight of the finished structure, since the weight of the protecting paint film, which is usually applied to the uncoated sheet, may be comparable with the added metal weight, particularly in the case of the thinner gauges commonly used in aircraft. The substitution of Alclad 24S-T for uncoated 17S-T will actually permit a saving in weight without any consideration of the weight of the protective paint film used with the latter material.

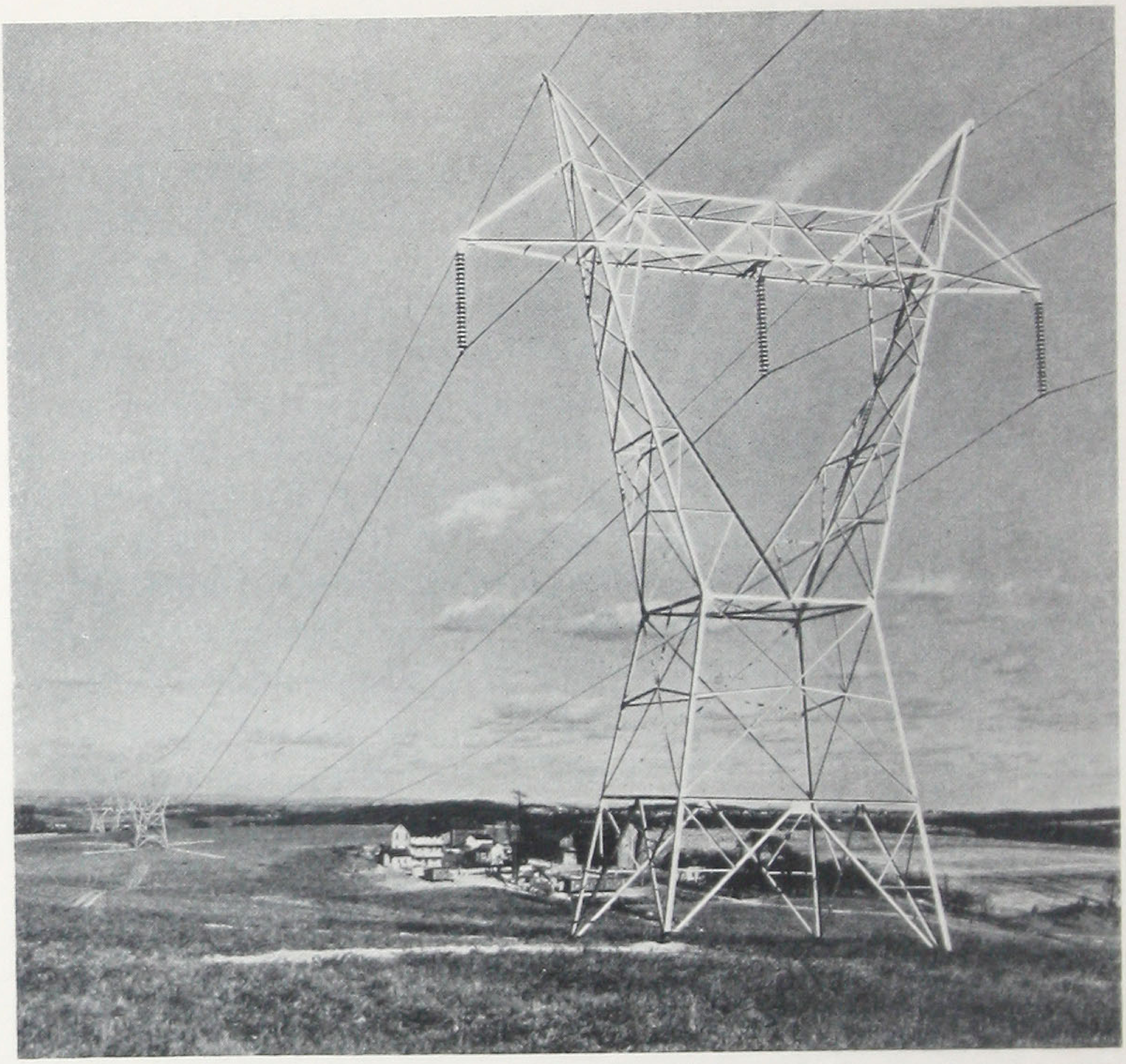
It should again be repeated that the corrosion problem is largely dependent upon the condition of exposure. All of these alloys are used in a considerable variety of applications because of their satisfactory performance as regards retention of their surface appearance and mechanical properties.

The section thickness also has considerable bearing on the suitability of the different alloys for a given application. In aircraft construction efficient design requires the extensive use of thin highly stressed sections with a minimum factor of safety. For such parts only the more resistant alloys and the best protective measures are employed.

For applications requiring the use of thicker sections, superficial surface attack which may occur under some conditions is of minor consequence. For such uses the relative resistance to corrosion becomes a less important factor in the choice among the aluminum alloys.

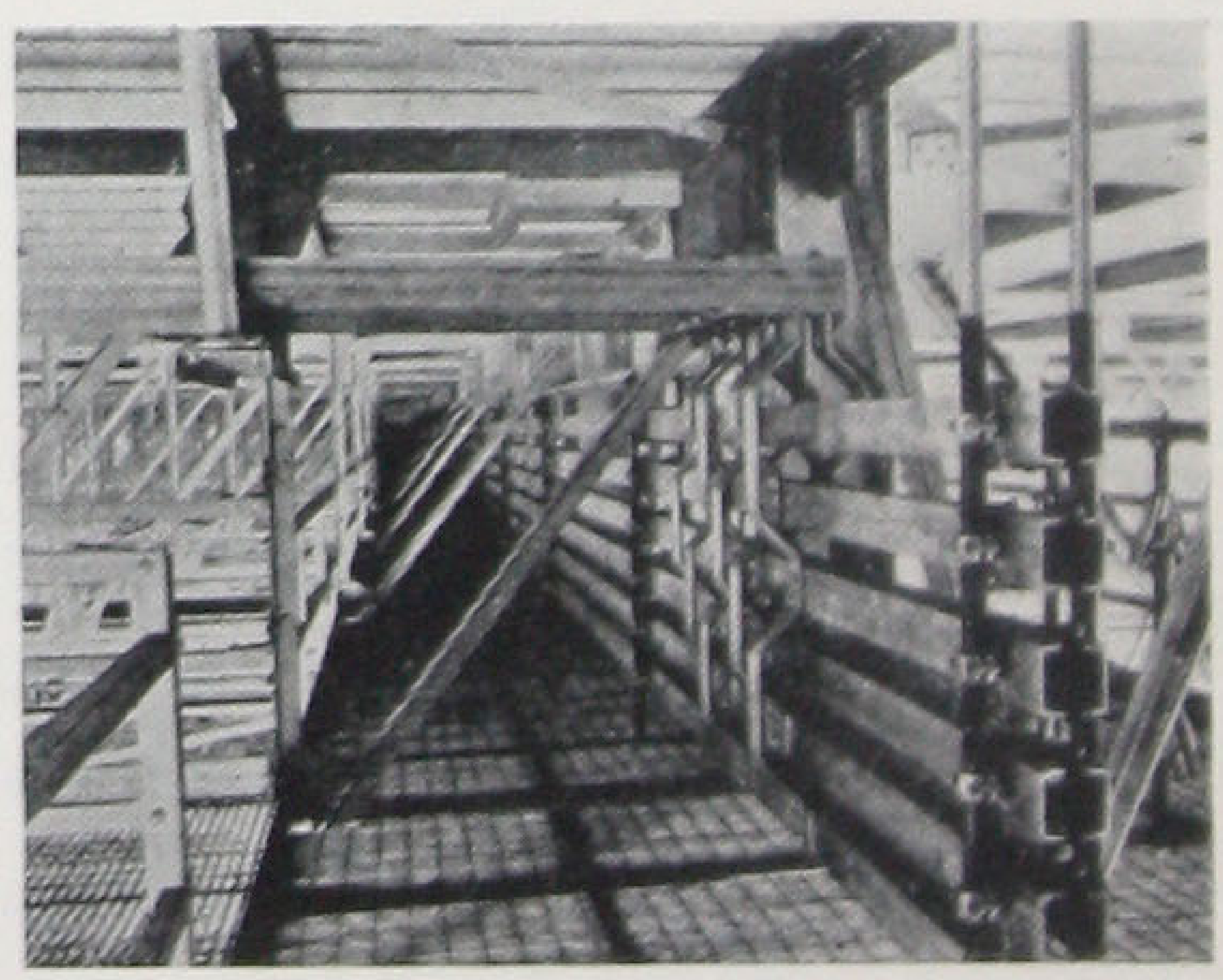
ANNEALING PRACTICE

The strain-hardening which results from cold working aluminum alloys may be removed by annealing, i.e., by heating to permit recrystallization to take place. The rate at which recrystallization occurs is greater, the higher the temperature and the more severely the metal has been worked before it is annealed. Com-



Over 400,000 miles of aluminum cable, steel reinforced, has been used for transmitting electrical energy in the United States alone. Its high strength-weight ratio gives an extra factor of mechanical safety.

Alcoa Aluminum bus bars provide long life, are cool in operation and easy to work.



Channel conductor, for heavy currents, will allow greater distance between the supports.

plete softening is practically instantaneous for 2S and 52S at temperatures in excess of about 650°F., and for 3S and 4S at temperatures of 750°F. or higher. Heating for longer times at somewhat lower temperatures will accomplish similar results. Provided the metal has reached the instantaneous annealing temperature, the exact temperature is not critical, although it is desirable that the recommended values shall not be too greatly exceeded. The rate of cooling is also not important, although too rapid cooling may impair the flatness of the material.

In the case of the heat-treatable alloys, greater care is required in the choice of annealing conditions. The metal must be raised to a temperature which will permit recrystallization in order that the strain-hardening shall be removed. On the other hand, the temperature must be maintained as low as possible in order to avoid heat-treatment effects which would prevent complete softening of the alloy, or else the cooling rate must be so slow as to counteract the effect of such heating (See Solution Heat Treatment, page 36).

Heating these alloys to 650°F. is sufficient to remove the strain-hardening which results from cold working. This temperature should not be exceeded by more than ten degrees, nor should the metal temperature in any part of the load be less than 630°F. The rate of cooling from the annealing temperature is not important if the maximum temperature limit has been observed, but slow cooling to a temperature of about 450°F. is a desirable precaution in case any part of the load may have been heated above this temperature.

This annealing practice, in addition to removing the hardening effects of cold working, also removes most of the effects of heat treatment when applied to metal in the heat-treated temper. For many purposes, this practice may be used to anneal the alloys in the heat-treated temper, provided the maximum degree of softness is not required for the forming which is to be done.

For more severe forming, which requires that the metal be in its fully-annealed condition, the following process must be used for metal in the heat-treated temper. The alloy is heated at a temperature of 750°F. to 800°F. for about two hours and is then allowed to cool slowly in the furnace to a temperature of 500°F. The cooling rate should not exceed 50°F. per hour.

SOLUTION HEAT-TREATMENT PRACTICE

It should be stated at the outset that accurate temperature control is necessary if proper results are to be obtained with strong aluminum alloys. The temperature limits for the solution heat treatment are rather close, and strict adherence to these limits is essential. Heating is, perhaps, most easily accomplished in a bath of fused sodium nitrate, heated with gas or oil so as to permit close regulation of the temperature. Such a bath should be well stirred to avoid inequalities in temperature. This can be readily accomplished by alternately raising and lowering the load while it is being heated, making sure, however, that the metal is not raised above the surface of the bath.

A furnace for heating in air can be used, provided it is so constructed as to give uniform temperatures throughout, and to permit proper control. These results are more easily accomplished if provision is made for circulating the air. Both types of heating are in commercial use. The temperature range for the heat treatment of 17S and A17S is from 930°F. to 950°F. For 51S and 53S, the temperature should be 970°F., making certain that the temperature is at least 960°F. and not over 980°F. For 24S, the temperature range is 910°F. to 930°F.

The time of heating depends upon the size of the load, the nature of the material, and the type of heating equipment. In a nitrate bath, a period of 25 minutes is usually sufficient; somewhat shorter times have given satisfactory results. In the furnaces in which air is the heating medium, the heating may require several hours. It is essential that all of the metal in all parts of the furnace load be raised to the specified temperature. Heating periods longer than the minimum which will accomplish the results are not detrimental within the limits that may be encountered in commercial fabricating practice.

Alclad alloy products should be heated as rapidly as possible and held for the minimum time which will insure that all of the load has been brought up to the heat-treating temperature. If long heating periods are used, the alloying constituents of the base metal will diffuse completely through the surface layer and the corrosion resistance of the product will be impaired. The thinner the material, the more essential it is that this precaution be observed.

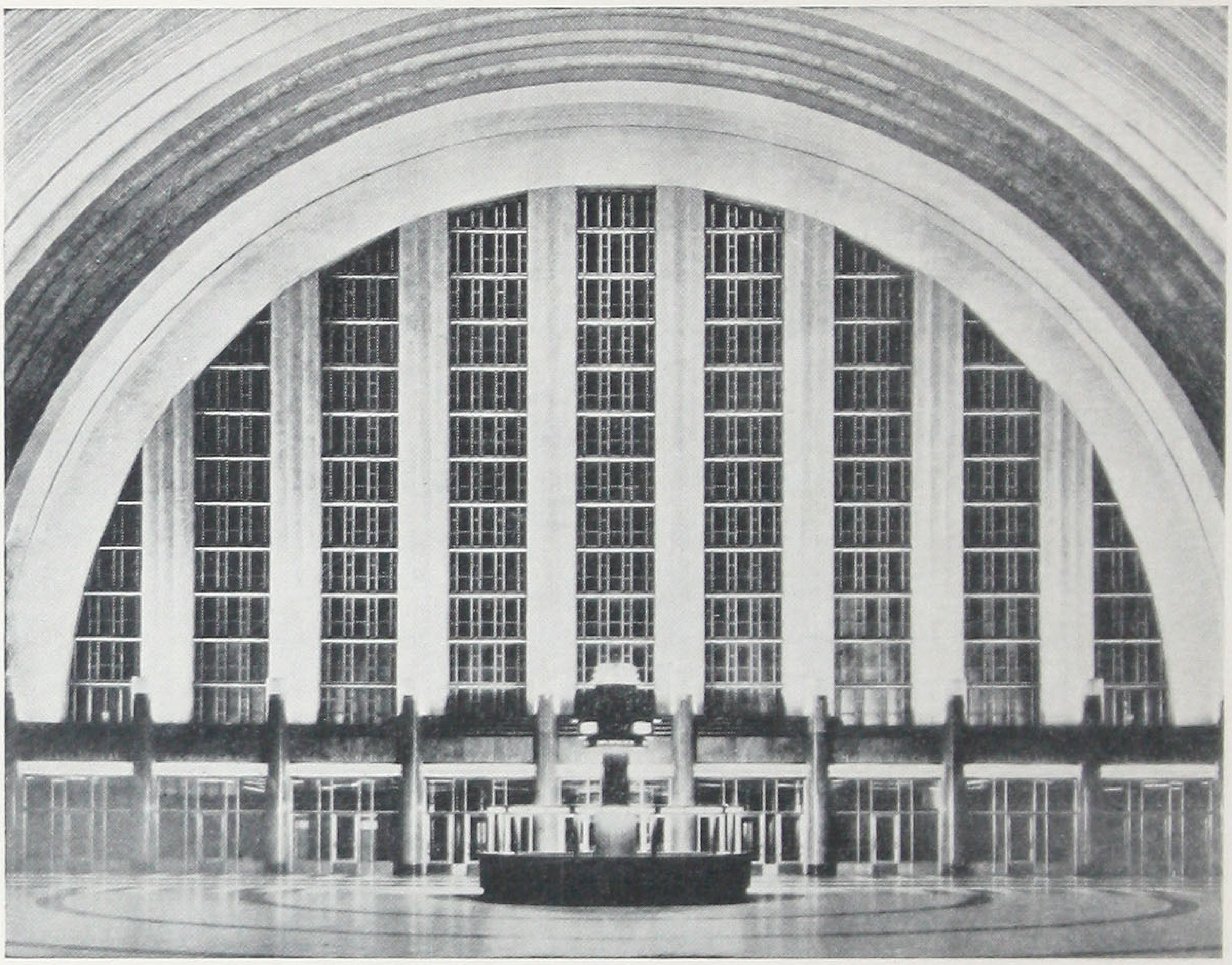
The metal is removed from the heating bath or furnace and quenched in water. The time interval between the removal of the metal and its quenching should be as short as possible, not more than a few seconds, if best results are to be obtained.

The quenching medium should be cold water. If hot water is used, the resistance of the alloy to corrosion is decidedly inferior. The effect of diffusion in Alclad products which have been heated too long is more harmful if they are not quenched in cold water. The volume of quenching water should be great enough that its temperature is not raised above 150°F. to 160°F. by the heat of the load. When a nitrate heating bath has been used, it is necessary that any adhering nitrate be completely washed from the metal in order to avoid corrosion because of the tendency of the salt to take up moisture; it may be desirable to follow the cold-water quench with a thorough washing in warm water because of the greater solubility and higher rate of solution of the salt at higher temperatures. The water should be warm, not hot, especially if the alloy is to be formed before it has aged.

The aging of 17S and 24S starts quite rapidly immediately after quenching and proceeds at a gradually diminishing rate until in about four days, at room temperature, it is practically complete. Severe forming of these alloys should be completed within one or two hours after quenching unless the rate of aging is retarded by storing them at low temperatures. If stored at the temperature of melting ice, immediately after quenching, good forming qualities may be retained for upwards of twenty-four hours, and at lower temperatures for even longer periods. On warming to room temperature, aging proceeds at the normal rate.

PRECIPITATION HEAT-TREATMENT PRACTICE

In order to develop the maximum strength in 51S and 53S, these alloys must be aged at an elevated temperature after they have been quenched. This operation, known as the precipitation heat treatment, may be readily accomplished in an oven heated by means of steam coils and provided with a fan for air circulation. The temperature can be varied by changing the pressure in the steam coils. An electric furnace of proper design will also give satisfactory results.



The main concourse of a new railroad station is a striking example of the use of aluminum in modern interior decoration. Doors, windows, lighting fixtures, grilles, clocks, and trim are typical appointments in aluminum.

This unusual memorial, made of alumilited aluminum, is 35 feet high, 30 feet long, and 20 feet wide. The wing spread of the largest gull is 6½ feet and that of the smallest is 4½ feet. Durable, strong aluminum is being used more and more in the field of statuary.

For 51S and 53S, the preferred temperature limits are 310°F. to 320°F., and the aging time is eighteen hours. Some experimentation may be required to determine the best aging time for a given class of material. It should be remembered that aging for too long a time or at too high a temperature will lower the elongation and eventually the tensile strength as well. If the temperature is too low, much longer aging periods are required to bring about the proper improvement of the alloys.

THEORY OF HEAT TREATMENT

In the aluminum alloys which respond to heat treatment, the alloying constituents which give the increased strength and hardness are substances which are more soluble in solid aluminum at high temperatures than at low temperatures.

The first step in heat treatment, frequently called the "solution heat treatment," consists in heating the alloy to a high temperature, below the melting point, to put as much as possible of the alloying constituent into solid solution, then quenching to retain this condition. When in solid solution, the alloying constituent is so finely dispersed that it is not visible with the microscope, even at high magnification. In effect, the alloying constituent has been dissolved in the aluminum and dispersed as completely as when sugar is dissolved in water.

After quenching, the alloy undergoes an aging process which, if carried out at elevated temperatures, is called a "precipitation heat treatment," because during this stage some of the alloying constituent which is held in solid solution precipitates from the solid solution in the form of extremely fine particles. This precipitation may occur spontaneously at room temperature, as is the case in the so-called "natural aging" of the alloys 17S and 24S, or it may require a "precipitation heat treatment" or "artificial aging" at about 300°F., as in the case of 51S or 53S.

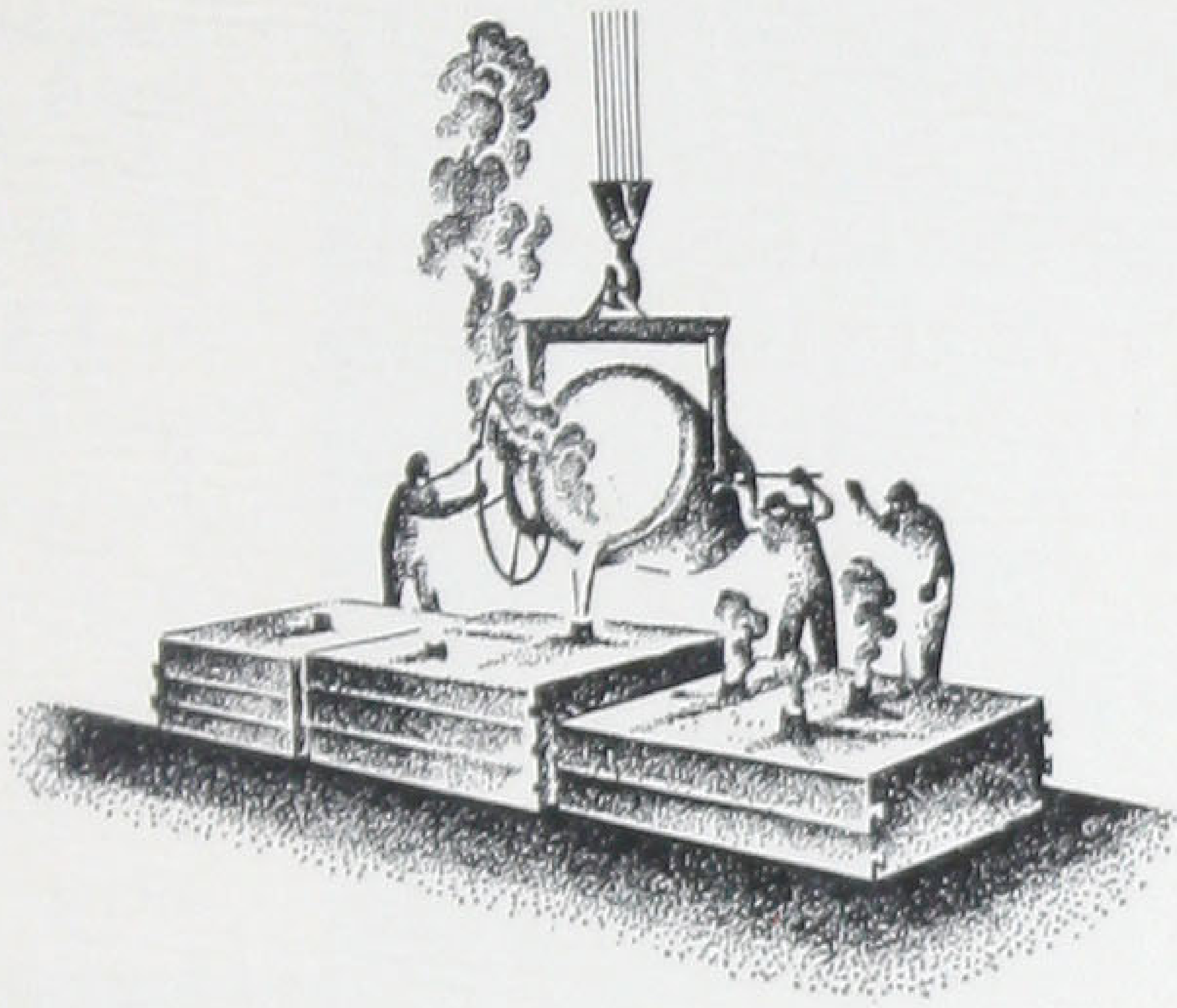
The particles of precipitated constituent may be so fine as to be invisible even under the most powerful microscopes, but their presence and effects are quite real, even though they cannot be seen. By continued heating they may, however, be caused to grow to sufficient size so that they become visible under microscopic examination. The size and distribution of the precipitated

constituent are highly important in determining the mechanical and physical properties of the heat-treated alloy. There is an optimum condition which gives the best combination of properties, and a detailed knowledge of the heat-treatment process is necessary to produce the best results with each alloy.

The increase in hardness of the alloy as a result of heat treatment is pictured as being due to the "keying" action of the precipitated particles of the alloying constituent, which prevents slip along the crystal planes of the metal. To use a simple analogy, the action might be compared with the effect of ashes which prevent the feet of pedestrians from slipping on icy pavements.

These changes with the corresponding increase in tensile properties, tend to take place at ordinary room temperatures. In the case of 17S and 24S the age hardening is practically complete in about four days.

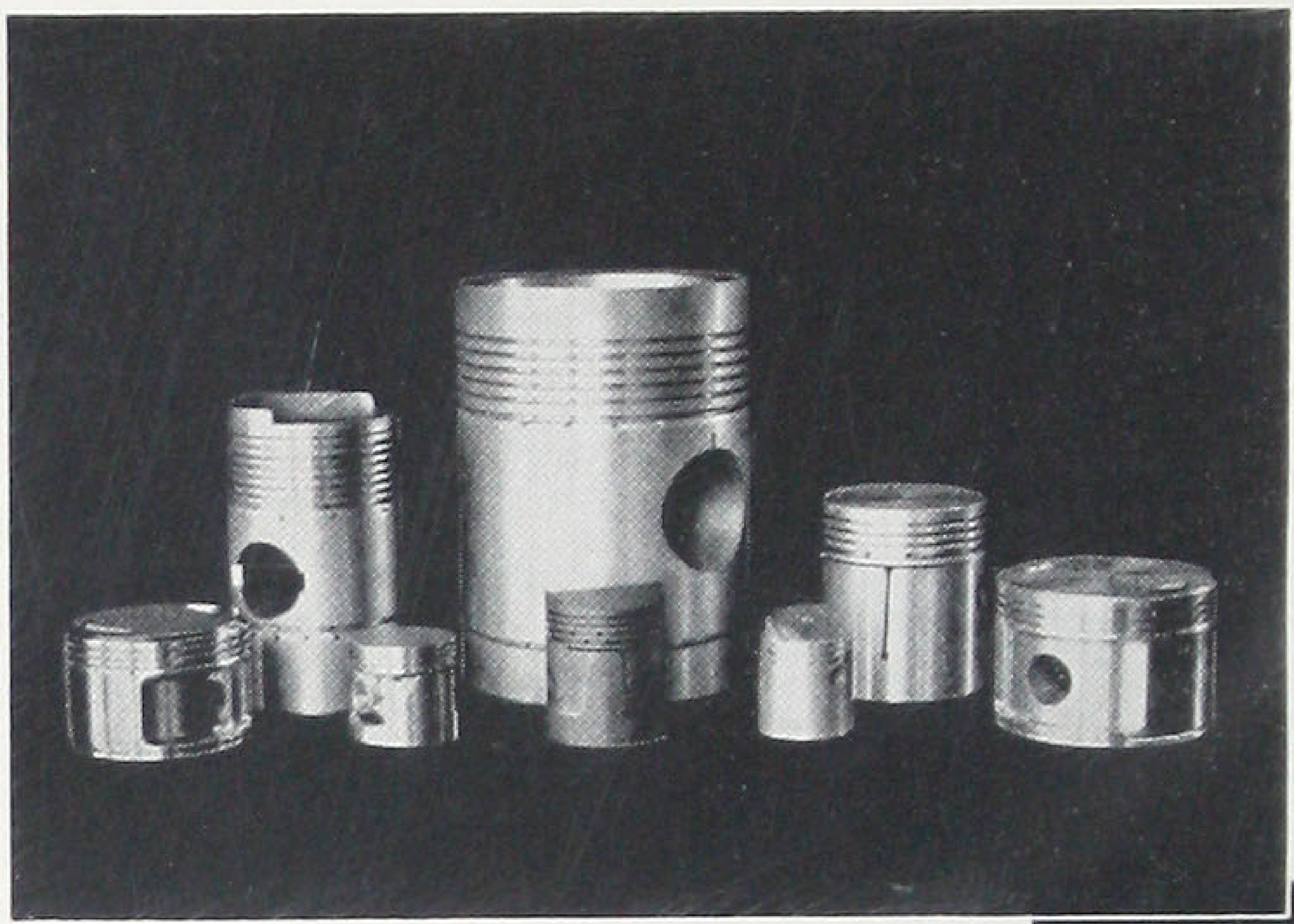
The alloys 51S and 53S likewise show some increase in strength and hardness on standing at room temperatures after quenching, but after several days the rate of change becomes very slow. If, however, the temperature is raised, the rate of precipitation and particle growth is materially increased, with the result that much higher tensile and yield strengths and hardness can be developed in these alloys in a few hours than would be possible at room temperature over an indefinite period. Some of the alloys show practically no change in properties on aging at room temperatures after quenching. At higher temperatures precipitation occurs with the consequent improvement in tensile properties. This second heating operation is called the "precipitation heat treatment". When the change occurs at ordinary temperatures, it is known as "aging".



CASTING ALLOYS

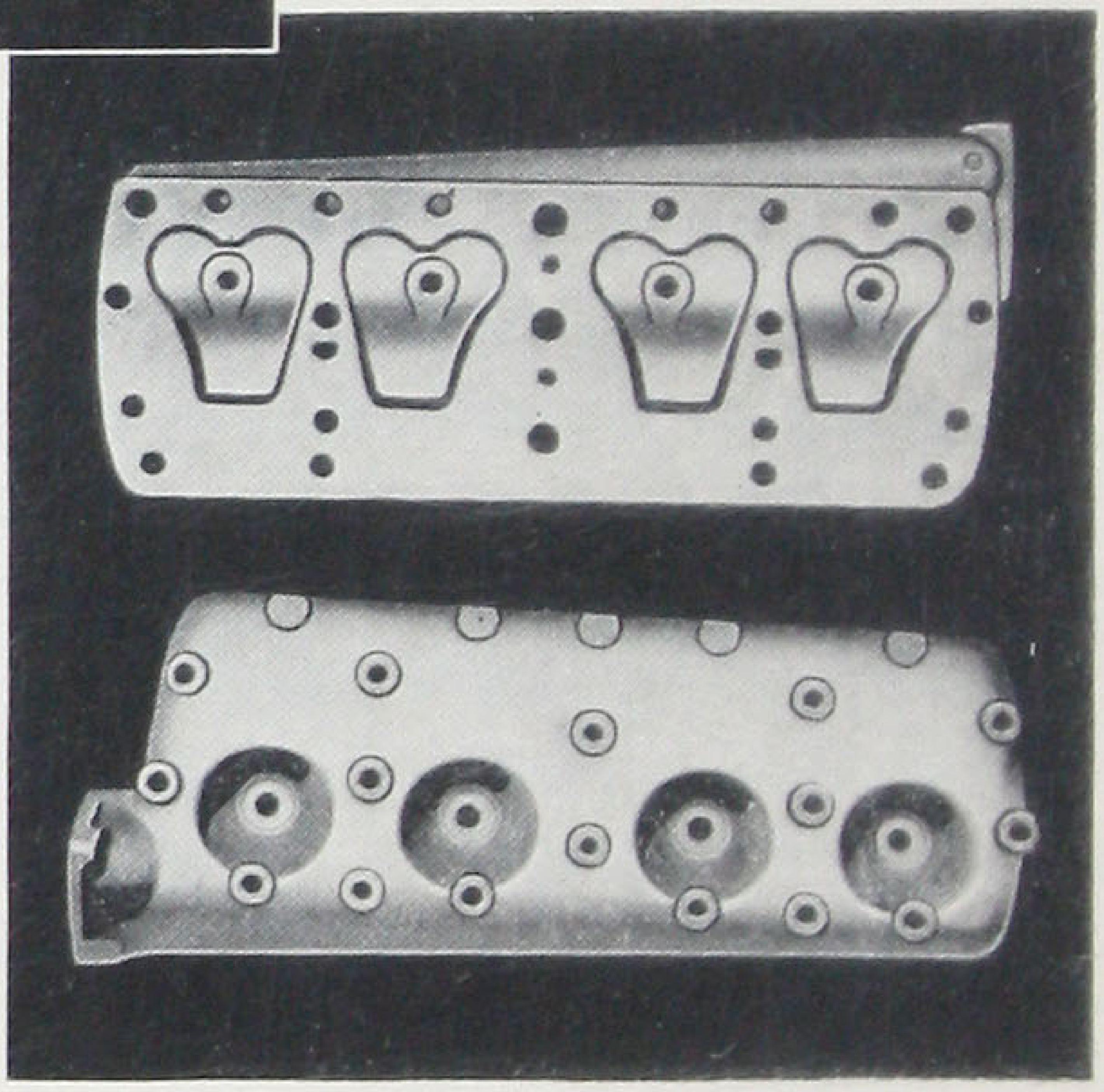
Aluminum casting alloys may, like the wrought alloys, be classed in two groups: one, in which the improvement in properties is accomplished by alloying alone; and two, the alloys in which heat-treatment processes are used to enhance further the mechanical properties. The casting alloys are given a number to designate the alloy composition; the heat-treatable alloy composition numbers are followed by the letter "T" and a number to indicate the heat-treatment practice. Minor changes in the composition are indicated by a letter preceding the original alloy number. As in the case of the wrought alloys, the selection will depend upon the requirements of the particular application.

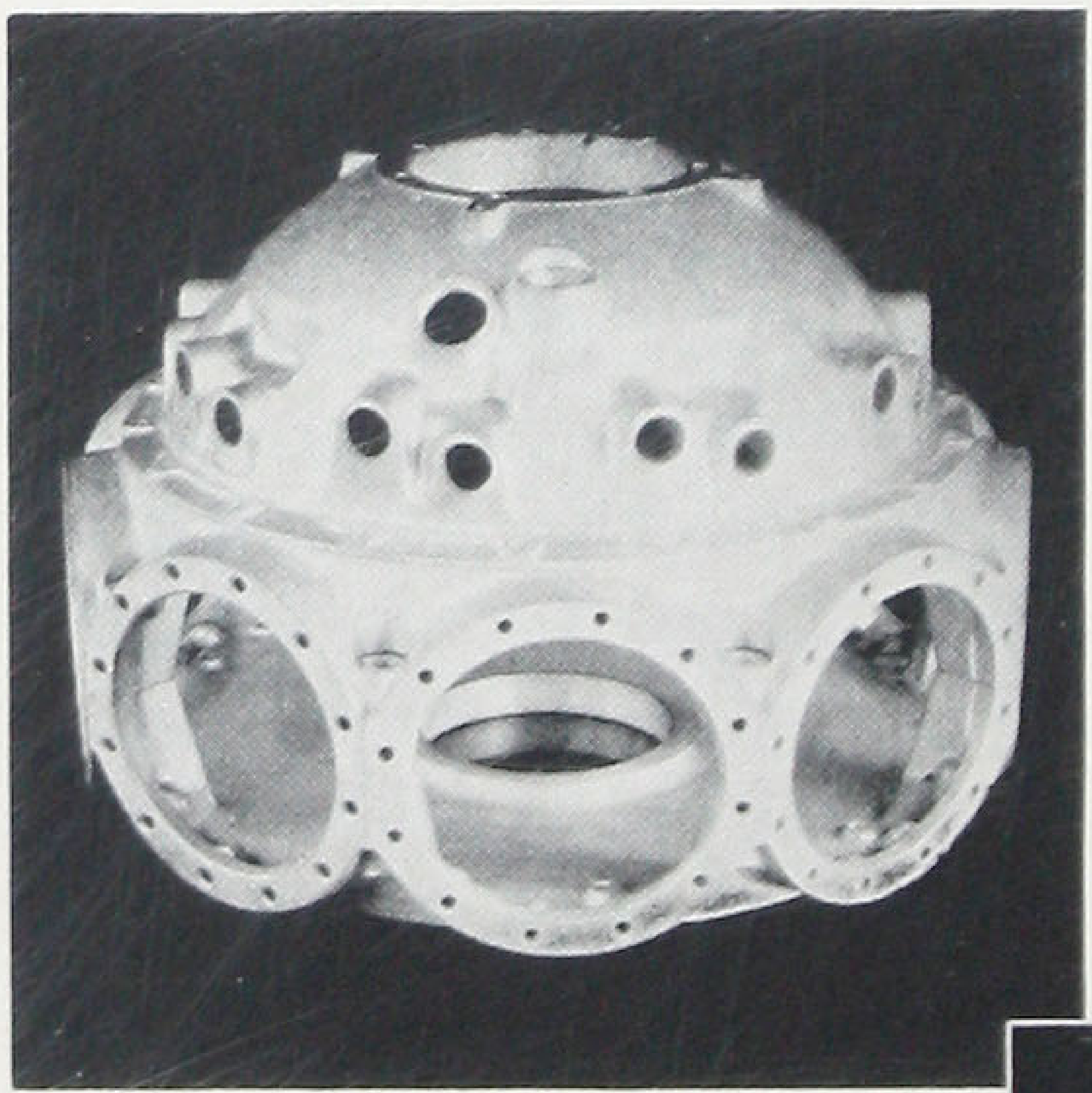
Castings are almost invariably produced in the alloys of aluminum except in a few cases where the electrical or other properties of the pure metal are required. By the addition of various alloying elements or "hardeners" to aluminum, not only its tensile strength, but casting properties as well, are improved. By alloying alone, strengths almost double that of commercially pure aluminum are obtained and the increase in strength is gained at a sacrifice of most of the ductility of the parent metal. The elements commonly used as hardeners are copper, silicon, magnesium, zinc, manganese, nickel and iron. The properties of the alloys vary depending upon the element or elements which are added and upon the percentages used. No two of the alloys in commercial use have identical properties, even though several of them may have substantially identical tensile strengths. A brief discussion of the



Left—Lightweight combined with thermal efficiency makes aluminum the universal choice for pistons.

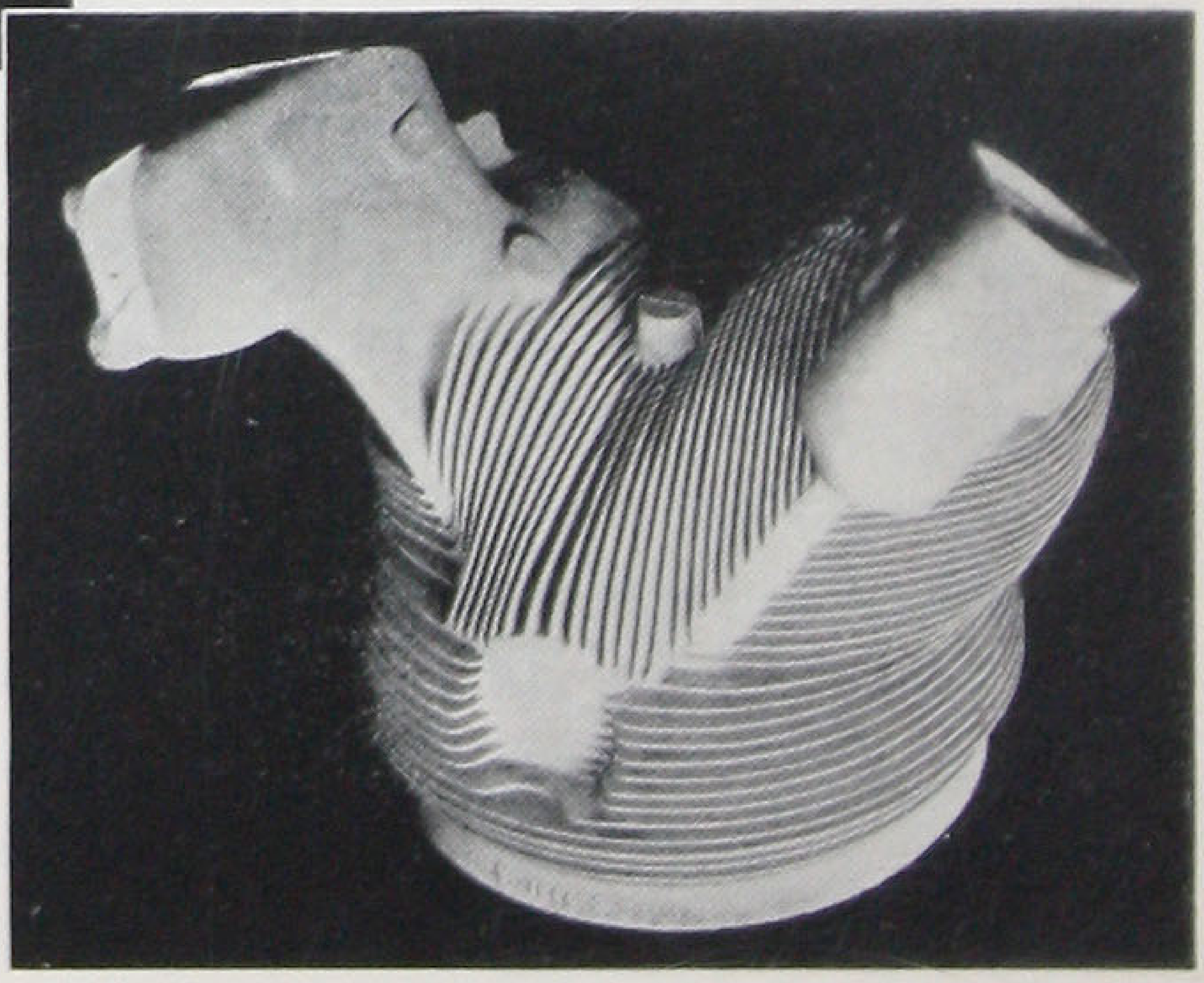
Right—Alcoa Aluminum cylinder heads are cast in a metal mold to assure superior accuracy and soundness.





Left—Forged aircraft crankcase.

Below—Sand cast aircraft cylinder head.



Continuous improvements in mechanical properties of aluminum alloys, and advances in foundry and forging practice are contributing to engine performance and life.

characteristic properties of the different alloys may be of value in addition to the tabulation of the mechanical properties which appear in Table 11.

Aluminum alloy castings are poured not only in sand molds, but in permanent metal molds; they are also die cast under pressure in die-casting machines. The type of casting process which is used will depend upon several factors. For large or for intricate cored castings, the use of sand molds is necessary. Because a metal mold or steel die is required, the use of die and permanent mold castings can be considered only where a sufficiently large number of castings of the same pattern will be used to justify the cost of the mold or die to the purchaser. The die-casting process is particularly adapted to the quantity production of relatively small castings in which close dimensional tolerances are required and the cost of finishing must be held to a minimum. The dimensional tolerances of permanent mold castings are intermediate between those of sand castings and those of die castings, and the surface finish is comparable with that of die castings.

The mechanical properties of test bars cast in metal molds are, in general, higher than those from the same alloy cast in sand. This same superiority in strength will be realized in commercial castings, except in so far as problems of mold design may partially offset the advantages of the better metal structure.

Sand Castings: The aluminum castings industry has developed from the use of an alloy called No. 12, containing about eight per cent of copper and such impurities as are present in commercial aluminum ingot. Sand molds were first used, permanent metal molds being a more recent introduction. The alloys 112 and 212 have been developed from the original 12 alloy. The greater proportion of the castings produced in this country is still made from these alloys, although the preponderance is not nearly as great as it was a few years ago.

From the standpoint of the finished castings, there is little to choose among alloys 12, 112, and 212. The mechanical properties are substantially the same. All three contain approximately eight per cent of copper; 212 differs from 12 in that small additions of silicon and iron are made to control the ratio of these elements and thereby improve the casting qualities of the alloy.

Alloy 112 contains small additions of iron and zinc. For most uses, these small differences in composition are not significant. Alloy 112 has somewhat superior machining qualities; however, except on large production jobs, this difference is probably not sufficient to determine the choice. For most applications, these alloys may be used interchangeably and they are commonly specified for general purpose castings. Where pressure tightness is required, 109 alloy is sometimes used, although it is not suitable where it may be required to withstand shock.

Alloy A-334 (U. S. Patent 1,572,489) has slightly better mechanical properties than those of 12, 112, and 212 alloys, as well as somewhat superior casting properties. It can be used for the production of castings of intricate design, in which pressure tightness is required. It may be subjected to an artificial aging treatment to increase its hardness and to improve its machining qualities (U. S. Patent 1,394,534).

Alloys containing silicon as the hardener have made a steady increase in commercial application since their introduction a few years ago, and today, these alloys represent a considerable percentage of the foundry production both in this country and abroad. They have excellent casting qualities and can be used in the production of large thin section castings, which are intricate in design, or of castings which have adjoining heavy and light sections; they are also employed in the production of castings which must withstand fluid pressures without leaking. In addition, the aluminum silicon alloys have excellent resistance to corrosion. Certain compositions are susceptible to heat treatment or to special foundry practices (modification) to improve their mechanical properties.

Alloy 43, containing five per cent of silicon, is most widely used in this country. Its tensile and yield strengths are somewhat lower than those of the aluminum-copper alloys (12, 112, 212), but it is appreciably more ductile and resistant to shock. Because of its excellent casting qualities and resistance to atmospheric attack, it is used practically to the exclusion of other alloys in the production of architectural and ornamental castings. Marine castings are also made of it because of its satisfactory performance in salt-laden atmospheres. Alloy 45, containing ten per cent silicon, has higher strength and hardness, but it is less ductile. It is

similar in other respects to 43 alloy, but not always quite so easily cast in leak-proof castings. Alloy 45 has been used in instrument frames and fittings because of its higher strength.

Alloy 47 contains twelve and one-half per cent silicon. When cast without the use of special casting practices (such as those described in U. S. Patents 1,387,900, 1,410,461, 1,596,020, 1,572,-459, 1,570,893, 1,848,797, 1,848,798), the alloy is quite brittle and has a coarse crystalline fracture. By the use of the "modification" process, sand castings can be produced having distinctly higher strengths than those of 43 and 45 alloys, and higher elongation as well. The fracture of the "modified" or the chill cast alloy is fine-grained, and is commonly designated as "silky."

Alloys containing magnesium in suitable proportions as the hardener, are even more resistant to corrosion than the aluminum-silicon alloys. Alloy 214, containing three and three-quarters per cent of magnesium, is used where service conditions require the maximum resistance to corrosive attack. It is more difficult to cast into intricate, leak-proof castings than the aluminum-silicon alloys, but has higher mechanical properties than 43 alloy and is distinctly more resistant to corrosion. It is employed in the production of castings for use in sewage disposal plants, chemical plants, and dairy equipment; it is also used in cast cooking utensils and for the production of aircraft and marine castings. Alloy 216, containing approximately six per cent magnesium, has higher tensile and yield strengths but somewhat lower elongation. Because of the higher magnesium content, special foundry technique is required for the production of satisfactory castings. Its resistance to corrosion is at least equal to that of 214 alloy.

For certain special applications, other compositions may be recommended. Alloy 108 (U. S. Patent 1,572,489) contains both silicon and copper and combines some of the desirable characteristics of these two classes of alloys. Zinc is sometimes used as a hardener for aluminum; in fact the alloy most commonly used in Europe contains zinc and copper as the alloying elements. For certain classes of castings, alloy 645 (U. S. Patent 1,352,271) is sometimes used; it is similar to the European type alloy, but contains iron as an essential constituent. Its mechanical properties are higher than those of the aluminum-copper or the aluminum-silicon alloys, but it is not advised for uses in which severe cor-

rosive conditions may be encountered. It also should not be used where it will be subjected to elevated temperatures in service because it has lower strength under these conditions than do most of the other aluminum alloys.

Permanent Mold Castings: Some of the alloys used in making sand castings are also poured into permanent molds, while others have been developed primarily for this purpose. The composition and physical properties of some of the more commonly-used permanent mold alloys are listed in Table 12. Because of the finer grain structure resulting from the rapid solidification of the metal, permanent mold castings have greater susceptibility to heat treatment, and in the case of the aluminum-silicon alloys, the structure and mechanical properties are similar to those obtained by the modification processes in sand castings (U. S. Patent 1,572,459).

The great majority of pistons for internal combustion engines have been made from 122 alloy. More recently 132 alloy (U. S. Patent 1,799,837) has been developed to provide a material with a lower coefficient of thermal expansion than that of other commercial alloys of aluminum. The use of this latter alloy permits a closer fit of the piston in the cylinder. Pistons for certain of the aircraft engines are made from 142 alloy. All of these alloys are susceptible to heat treatment for improvement of their mechanical properties (U. S. Patents 1,394,534, 1,572,487, 1,572,488, 1,508,556, 1,713,093, 1,822,877, 1,945,737, etc.).

Alloys containing approximately eight per cent copper as the principal alloying constituent, also find application in permanent mold castings. Although alloy 112 is used to some extent, variations of this alloy, known as B113 and C113, have been developed particularly for this use. Controlled additions of silicon and zinc in these latter alloys provide the somewhat better casting characteristics desired for permanent mold use.

Alloy A108, containing both copper and silicon, and combining some of the desirable characteristics of both classes of alloys, possesses good casting properties for the more intricate permanent mold castings.

Alloys 138 and 144 provide excellent hardness in the cast condition, which hardness is retained well at elevated temperatures.

Alloy 138, particularly, has found applications for parts, such as flat-iron sole plates, where maximum hardness at operating temperatures is desired.

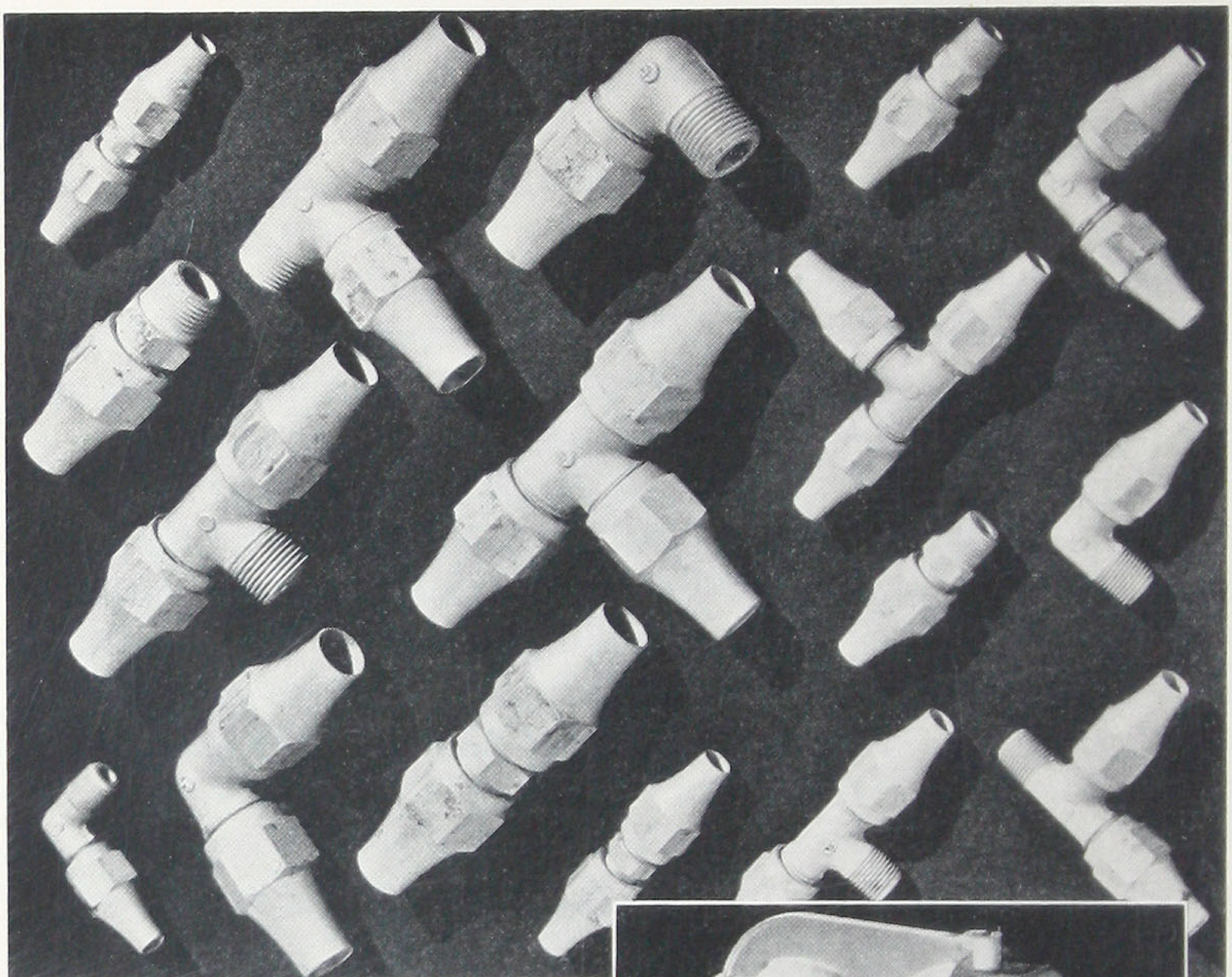
Alloy A214 is a modification of the sand casting alloy 214, developed because of its superior qualities for casting in permanent molds. Its tarnish resistance is substantially the same as that of the sand casting alloy from which it was developed.

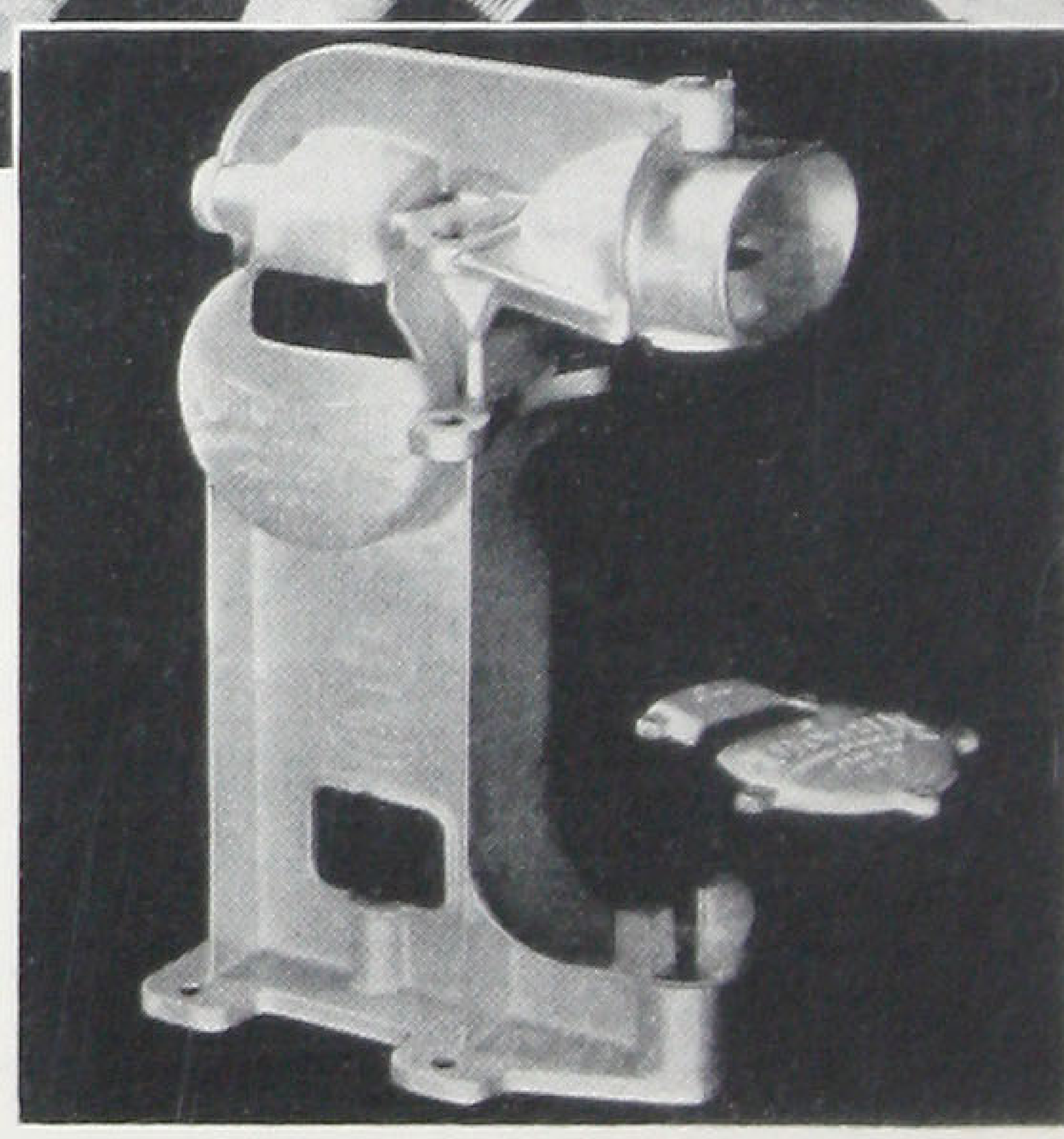
The selection of an alloy for a permanent mold casting depends both upon the nature of the casting and upon the service it is to perform. This question can best be decided by consultation with a representative of the Company, who is familiar with the production and the properties of permanent mold castings. Where this process is applicable, it offers not only the mechanical advantages which have been mentioned, but closer dimensional tolerances. Finishing costs may be materially lower than those for sand castings as a result of the saving in machining.

Heat-Treated Castings: The production of heat-treated castings has increased over the past several years in response to the increasing demand for lightweight castings having mechanical properties superior to those of the common unheat-treated casting alloys.

The alloy which has come into most general use is No. 195, containing four per cent copper. Solution heat treatment (T4) (U. S. Patent 1,572,487) causes a marked increase in the tensile and yield strengths and also higher elongations as compared with the alloy as cast. If the solution heat treatment is followed by a precipitation heat treatment (U. S. Patent 1,394,534), the tensile and yield strengths are increased and the elongation is decreased. The extent to which these changes occur vary with the time and temperature which are employed. Alloy 195-T6 has a higher tensile and yield strength, and an elongation about half that of 195-T4. If, however, this latter alloy is allowed to age at room temperature for several months, properties nearly the same as those of 195-T6 are developed. Still higher tensile and yield strengths are obtained in alloy 195-T62, but the increase in these properties is obtained at the sacrifice of most of the elongation of the alloy.

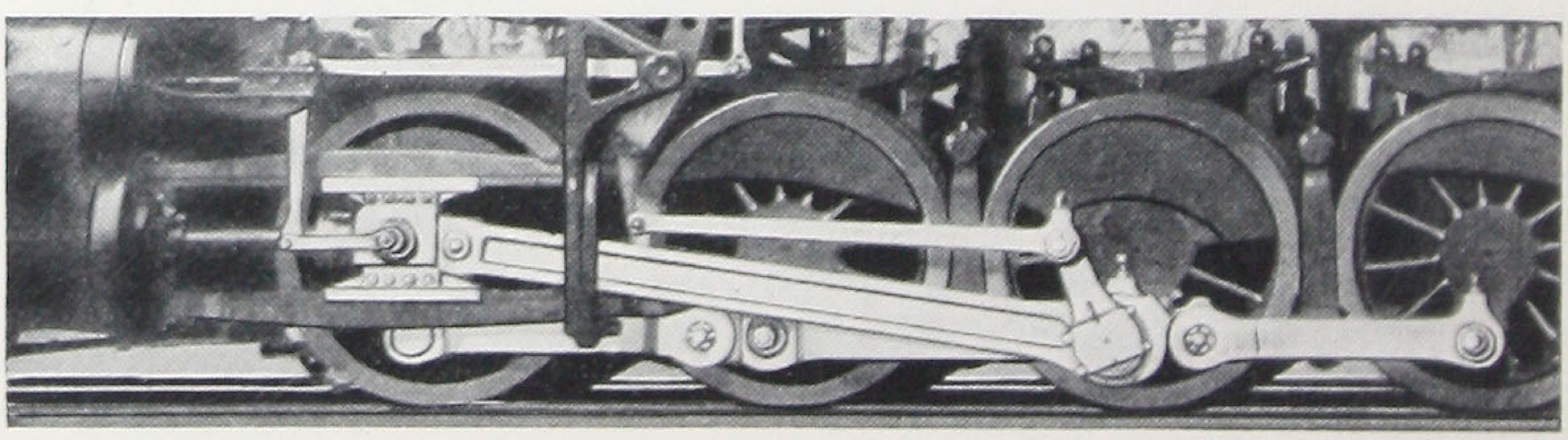
For use in permanent molds the heat-treated four per cent cop-





Above—Standard flared type fittings, machined from forged blanks, simplify the use of Alcoa Aluminum tubing for fuel and oil lines.

Right—For quantity production, Alcoa Aluminum die castings offer thin sections, smooth surfaces, close dimensional accuracy.



Forged aluminum locomotive connecting rods and cast heat-treated cross-head assemblies reduce inertia and centrifugal forces and are durable in service.

per alloy composition is modified by the addition of three per cent of silicon (U.S. Patents 1,508,556, 1,572,489). The symbol for designating this composition becomes B195, and since it is regularly supplied in the solution heat-treated condition, castings are specified as B195-T4. A second modification known as D195 alloy, also supplied in the T4 condition, provides somewhat better mechanical properties than B195-T4, but, because of its less satisfactory casting characteristics, is limited to castings of relatively simple design.

For very complicated castings which, if produced in the unheat-treated alloys, would require the use of one of the aluminum-silicon alloys for successful or economical manufacture, a new high strength alloy has been developed. This alloy, 356 (U. S. Patents 1,472,739, 1,508,556, etc.) contains silicon and magnesium as hardening agents and, like 195, responds to heat-treatment processes. It is recommended for the production of castings in which superior mechanical properties are desired, but which would be difficult or uneconomical to manufacture in 195 alloy because of foundry limitations.

Like 195 alloy, 356 alloy is produced in several heat treatments, the most common of which are 356-T4, and 356-T6, the properties varying in the same manner as in the case of the former alloy. The mechanical properties are slightly lower than those of 195 as determined from standard test bars. A complicated casting made in this alloy may, however, be stronger than if it were made in 195, because of the avoidance of casting defects which could not be avoided in producing it from the latter alloy. For ordinary work, however, 195 alloy is usually recommended because of its long record of satisfactory performance and its greater ruggedness in withstanding shock or suddenly-applied load.

Alloy 355 (U. S. Patents 1,508,556, 1,848,816, etc.) containing slightly more copper and less silicon, also has excellent casting qualities, and, in addition, retains its strength well at temperatures up to 400°F. Like the other alloys in this group, it is susceptible to a variety of heat treatments to develop different properties. It is used in the manufacture of liquid-cooled cylinder heads for motors and for other complicated castings where its leak-proof properties and heat-resisting qualities are of importance. In case higher temperatures are to be withstood, the

modification of the alloy A355 (U. S. Patents 1,595,058, 1,848,-816, etc.) is recommended.

Both 355 and 356 alloys are susceptible to improvement in tensile strength and hardness, at some sacrifice in ductility, through an aging treatment alone. These treatments are of particular advantage for large and intricate castings whose design does not permit the standard quenching treatment without the introduction of undesirable quenching stresses. Aging treatments are also desirable for castings used at elevated temperatures and for controlling the "growth" in castings where this factor must be considered.

Alloy 220-T4 has the highest combination of tensile and yield strengths, elongation and impact resistance of any of the aluminum casting alloys. This alloy contains ten per cent magnesium, and for this reason, requires special foundry technique (covered by several U. S. Patents) to avoid oxidation of the magnesium from the surface of the metal with the consequent darkening of the casting and loss in mechanical properties. Alloy 220-T4 possesses exceptional machining characteristics and finds application for certain sand castings in which free cutting characteristics are desired.

The choice of an alloy for any particular application may usually be made from the physical properties and the general characteristics of the various alloys which have been discussed. The services of the technical staff of this Company are also available, on request, to assist in the selection of the alloy which is best suited for any requirement.

Die Castings: Die castings of aluminum alloys have the advantages of lightness, corrosion resistance and permanence of dimensions as compared with some of the other metals which are used in the die-casting process. Several alloys are cast in this manner, those which are recommended by this Company being shown in Table 18, together with their approximate compositions and mechanical properties.

In the case of die castings, the choice of alloy is determined in some measure by the nature of the casting. The different alloys have different casting characteristics, and the ability to produce the most satisfactory casting of the given design may often be

the deciding factor in the selection of the alloy, rather than the mechanical properties as determined from a test specimen. The die-casting specialist should be consulted both as to the possibilities of this product and the selection of the alloy.

Die castings offer the maximum advantages from the standpoint of low finishing costs because of their accuracy of dimensions and good surface. Savings also result because of the ability to cast thinner sections than are possible by other methods.

DESIGN OF ALUMINUM ALLOY CASTINGS

The mechanical properties of the various alloys referred to in the foregoing section and contained in the tables of the Appendix, are values obtained from standard A.S.T.M. ½″ diameter test specimens separately cast and tested without machining the gauge section. These test specimens are cast under conditions which duplicate as closely as possible the conditions of solidification of the casting. When cast under such standard conditions, these test specimens serve as a control of the metal quality, and in the case of heat-treated alloys, they also serve as a control of the heat-treating process, since they must be heat treated with the castings they represent.

The properties of separately cast test specimens do not necessarily represent the properties of commercial castings, and may be either higher or lower depending on a number of factors which influence the rate of solidification of the metal from the molten state. For the same reasons, the properties of test specimens machined from castings will vary depending on the location from which they are taken. Such foundry considerations as section thickness, gating and risering, chilling, pouring temperature, permeability and moisture content of sand, and any other factors which influence the rate of metal solidification, have a material effect on the mechanical properties.

These relations are not peculiar to aluminum alloy castings but exist in castings of all metals. They introduce two specific problems for the designer of cast metal parts; first, the selection of the proper alloy for such parts considering such factors as foundry characteristics and physical properties; and second, the selection of the proper factor to apply to the properties specified

for an alloy in determining the design stress. Such factors must take into account the type of service in which a casting will be used as well as the variation in the properties of the sections of each commercial casting. There is no known "rule of thumb" from which these factors can be determined, and in fact most designers develop their particular method from experience with specific metals and types of castings. The properties of test specimens machined from the specific casting being designed and proof load or breakdown tests on the casting assuming service loading conditions, provide data which are extremely useful in this connection if either the design or application of the casting is new. The latter method, particularly, is finding favor as a means of checking the design of aluminum alloy castings.

The services of the engineering and technical staffs of this Company are available on request to assist in the selection of alloys for casting applications as well as the designing of cast parts.

MECHANICAL PROPERTIES OF ALUMINUM ALLOYS AT HIGH AND LOW TEMPERATURES

In common with other materials, the tensile strength, yield strength and modulus of elasticity of aluminum alloys are lower at elevated temperatures than they are at ordinary temperatures. The elongation increases as the temperature is raised until at a temperature a little below the melting point it drops nearly to zero. This corresponds to the "hot short" range of the metal.

Factors to apply to the mechanical properties at ordinary temperatures, when designing for high temperature service, are shown in Table 7.

Tests made at a temper of –114°F. have shown that both the tensile strength and elongation are higher than at ordinary temperatures.

APPENDIX

APPENDIX

INTRODUCTION

IN THE Appendix will be found tables showing the physical properties, compositions, typical mechanical properties, guaranteed minimum mechanical properties, dimension tolerances and available commercial sizes of the various aluminum alloys and aluminum alloy products. Attention is called to the fact that the typical properties of the alloys represent approximate average values for use in comparison with similar values commonly given for other materials and, obviously, cannot be used in purchase specifications for the various alloy products. The available alloys and the limiting sizes shown for the different commodities represent normal commercial practice. It may be possible in some cases to exceed those limits or to produce the commodity in other alloys. Inquiries for such special material should be taken up with the nearest sales office of the Company (See page 92).

In a general discussion of aluminum and its alloys, it is not possible to anticipate nor to discuss adequately all questions which may arise in connection with the selection and use of aluminum alloys. Other booklets covering subjects such as:

MACHINING ALUMINUM AND ITS ALLOYS
THE RIVETING OF ALUMINUM
THE WELDING OF ALUMINUM

also booklets and other literature dealing with the use of aluminum in specific fields, such as the Dairy, Brewing, Power (Bus Bar and Cable Conductors) Chemical, and Food processing and packaging industries, may be obtained on application to the nearest sales office of the Company (See page 92).

Moreover, the advice and assistance of the sales representatives and through them of the Technical and Engineering Staffs of the Company are available to users or prospective users of aluminum products.

APPENDIX

TABLE 1—STANDARD COMMODITIES
WROUGHT ALLOYS

(Commodities marked * are standard.)

Alloy	Sheet	Plate	Wire	Rod and Bar	Rolled Shapes	Ex-truded Shapes	Tubing and Pipe	Rivets	Forg-ings
2S	*	*	*	*	.....	*	*	*	....
3S	*	*	*	*	.....	*	*	*	....
4S	*	*	....	....	.....	....	....	....	....
11S	....	....	....	*	.....	....	....	....	*
14S	....	....	....	....	.....	....	....	....	*
17S	*	*	*	*	*	*	*	*	*
Alclad 17S	*	....	....	....	.....	....	....	....	....
A17S	....	....	....	....	.....	....	....	*	....
18S	....	....	....	....	.....	....	....	....	*
24S	*	....	....	....	.....	*	*	....	....
Alclad 24S	*	....	....	....	.....	....	....	....	....
25S	....	....	....	....	.....	....	....	....	*
32S	....	....	....	....	.....	....	....	....	*
51S	*	*	*	*	.....	*	*	....	....
A51S	....	....	....	....	.....	....	....	....	*
52S	*	*	*	*	.....	....	*	....	....
53S	*	*	*	*	.....	*	*	*	*
70S	....	....	....	....	.....	....	....	....	*

*Commodities marked * are regularly produced in routine commercial production. Sales representatives of Aluminum Company of America should be consulted concerning the possibility of obtaining other commodities in the various alloys. For list of sales offices see page 92.

TABLE 2—NOMINAL COMPOSITION OF WROUGHT ALUMINUM ALLOYS#

Alloy	Per Cent of Alloying Elements. Aluminum and Normal Impurities Constitute Remainder							
	Copper	Silicon	Man-ganese	Mag-nesium	Zinc	Nickel	Chro-mium	Tin
2S	......	......	......	......	....	....	....	....
3S	......	......	1.25	......	....	....	....	....
4S	......	......	1.25	1.0	....	....	....	....
14S	4.4	0.8	0.75	0.35	....	....	....	....
17S	4.0	......	0.5	0.5	....	....	....	....
A17S	2.5	......	......	0.3	....	....	....	....
18S	4.0	......	......	0.5	....	2.0	....	....
24S	4.2	......	0.5	1.5	....	....	....	....
25S	4.5	0.8	0.8	......	....	....	....	....
32S	0.8	12.0	......	1.0	....	0.8	....	....
51S	......	1.0	......	0.6	....	....	....	....
A51S	......	1.0	......	0.6	....	....	0.25	....
52S	......	......	......	2.5	....	....	0.25	....
53S	......	0.7	......	1.25	....	....	0.25	....
70S	1.0	......	0.7	0.4	10.0	....	....	....

TABLE 3—APPROXIMATE COMPOSITION OF ALUMINUM SAND CASTING ALLOYS#

Alloy	Per Cent of Alloying Elements. Aluminum and Normal Impurities Constitute Remainder						
	Copper	Iron	Silicon	Zinc	Mag-nesium	Nickel	Man-ganese
12	8.0	....	....	....	....	....	....
43	....	....	5.0	....	....	....	....
47	....	....	12.5	....	....	....	....
108	4.0	....	3.0	....	....	....	....
109	12.0	....	....	....	....	....	....
112	7.5	1.2	....	1.5	....	....	....
122	10.0	1.2	....	....	0.2	....	....
142	4.0	....	....	....	1.5	2.0	....
195	4.0	....	....	....	....	....	....
212	8.0	1.0	1.2	....	....	....	....
214	....	....	....	....	3.75	....	....
216	....	....	....	....	6.0	....	....
220	....	....	....	....	10.0	....	....
A334	3.0	....	4.0	....	0.3	....	....
355	1.25	....	5.0	....	0.5	....	....
A355	1.4	....	5.0	....	0.5	0.75	0.75
356	....	....	7.0	....	0.3	....	....
645	2.5	1.5	....	11.0	....	....	....

Heat-treatment symbols have been omitted since composition does not vary for different heat-treatment practices. #The compositions and/or heat treatment of many of these alloys are patented.

TABLE 4—PROPERTIES OF WROUGHT ALLOYS

Wrought Alloys	Specific Gravity	Weight Lbs. per Cu. In.	Electrical Conductivity Per Cent of International Copper Standard	Thermal Conductivity at 100°C C.G.S. Units
2S-O	2.71	0.098	59	.53
2S-H	2.71	0.098	57	.51
3S-O	2.73	0.099	50	.45
3S-¼H	2.73	0.099	42	.38
3S-½H	2.73	0.099	41	.37
3S-H	2.73	0.099	40	.36
4S-O	2.72	0.098	42	.36
4S-½H	2.72	0.098	42	.36
4S-H	2.72	0.098	42	.40
14S-O	2.80	0.101	50	.45
14S-T	2.80	0.101	35	.32
17S-O	2.79	0.101	45	.40
17S-T	2.79	0.101	30	.27
18S-O	2.80	0.101	45	.40
18S-T	2.80	0.101	35	.32
24S-O	2.77	0.100	50	.45
24S-T	2.77	0.100	30	.27
25S-O	2.79	0.101	50	.45
25S-W	2.79	0.101	35	.32
25S-T	2.79	0.101	35	.32
32S-O	2.66	0.096	40	.36
32S-T	2.66	0.096	35	.32
51S-O	2.69	0.097	55	.50
51S-W	2.69	0.097	45	.40
51S-T	2.69	0.097	45	.40
A51S-O	2.69	0.097	50	.45
A51S-W	2.69	0.097	40	.36
A51S-T	2.69	0.097	40	.36
52S-O	2.67	0.096	35	.32
52S-H	2.67	0.096	35	.32
53S-O	2 69	0.097	45	.40
53S-W	2.69	0.097	40	.36
53S-T	2.69	0.097	40	.36
70S-O	2.91	0.105	40	.36
70S-T	2.91	0.105	35	.32

TABLE 5—APPROXIMATE RADII FOR 90° COLD BEND OF ALUMINUM AND ALUMINUM ALLOY SHEET

Minimum permissible radius* varies with nature of forming operation, type of forming equipment, and design and condition of tools. Minimum working radius for given material or hardest alloy and temper for a given radius can be ascertained only by actual trial under contemplated conditions of fabrication.

See Table 13 for thicknesses of sheet available in tempers produced by cold rolling.

Alloy and Temper	Bend Classification**	Alloy and Temper	Bend Classification**
2S-O	A	A17S-O	B
2S-¼H	B	A17S-T	F
2S-½H	B		
2S-¾H	D	24S-O(1)	B
2S-H	F	24S-T(1)(2)	J
		24S-RT(1)	K
3S-O	A		
3S-¼H	B	51S-O	A
3S-½H	C	51S-W	F
3S-¾H	E	51S-T	K
3S-H	G		
4S-O	B	52S-O	A
4S-¼H	D	52S-¼H	C
4S-½H	E	52S-½H	D
4S-¾H	G	52S-¾H	F
4S-H	H	52S-H	G
17S-O(1)	B	53S-O	A
17S-T(1)(2)	H	53S-W	F
17S-RT(1)	J	53S-T	G

*See page 24.
**For corresponding bend radii see following table:

RADII REQUIRED FOR 90° BEND IN TERMS OF THICKNESS, t

		Approximate Thickness					
B & S Gauge		26	20	14	8	5	2
Inch		0.016	0.032	0.064	0.128	0.189	0.258
Inch		1/64	1/32	1/16	1/8	3/16	1/4
Bend Classification	A	0	0	0	0	0	0
	B	0	0	0	0	0–1t	0–1t
	C	0	0	0	0–1t	0–1t	½t–1½t
	D	0	0	0–1t	½t–1½t	1t–2t	1½t–3t
	E	0–1t	0–1t	½t–1½t	1t–2t	1½t–3t	2t–4t
	F	0–1t	½t–1½t	1t–2t	1½t–3t	2t–4t	2t–4t
	G	½t–1½t	1t–2t	1½t–3t	2t–4t	3t–5t	4t–6t
	H	1t–2t	1½t–3t	2t–4t	3t–5t	4t–6t	4t–6t
	J	1½t–3t	2t–4t	3t–5t	4t–6t	4t–6t	5t–7t
	K	2t–4t	3t–5t	3t–5t	4t–6t	5t–7t	6t–10t

(1) Alclad 17S and Alclad 24S can be bent over slightly smaller radii than the corresponding tempers of the uncoated alloy.

(2) Immediately after quenching, these alloys can be formed over appreciably smaller radii.

TABLE 6—AVERAGE COEFFICIENT OF THERMAL EXPANSION PER DEGREE FAHRENHEIT

Alloy	Temperature Range		
	68–212°F.	68–392°F.	68–572°F.
2S, 3S, 4S	0.0000133	0.0000138	0.0000144
14S, 17S, 18S, 25S	0.0000122	0.0000130	0.0000138
32S	0.0000108	0.0000114	0.0000119
51S	0.0000130	0.0000136	0.0000141
53S	0.0000130	0.0000136	0.0000141
70S	0.0000136	0.0000144	0.0000150
12	0.0000125	0.0000130	0.0000136
43	0.0000122	0.0000127	0.0000133
47	0.0000111	0.0000113	0.0000119
108, 109, 112, 113	0.0000122	0.0000127	0.0000133
122	0.0000122	0.0000127	0.0000130
132	0.0000105	0.0000111	0.0000116
142	0.0000125	0.0000130	0.0000136
144	0.0000119	0.0000125	0.0000127
195	0.0000127	0.0000133	0.0000138
B195	0.0000122	0.0000127	0.0000133
D195	0.0000127	0.0000133	0.0000138
212	0.0000122	0.0000127	0.0000133
214, 216	0.0000133	0.0000138	0.0000144
220	0.0000136	0.0000141	0.0000147
A334, 355	0.0000122	0.0000127	0.0000133
A355	0.0000119	0.0000125	0.0000130
356	0.0000119	0.0000127	0.0000130
Brass	0.0000107		
Cast Iron	0.0000059		
Copper	0.0000093		
Lead	0.0000150		
Monel	0.0000078		
Nickel	0.0000057		
Steel	0.0000061		
Zinc	0.0000165		

TABLE 7—FACTORS FOR DESIGN STRESSES AT ELEVATED TEMPERATURES

	Alloy	100°F.	200°F.	300°F.	400°F.	500°F.
WROUGHT	3S-O	1.0	0.85	0.70	0.60	0.40
	3S-½H	1.0	0.75	0.60	0.45	0.30
	3S-H	1.0	0.75	0.60	0.35	0.25
	4S-O	1.0	0.90	0.80	0.50	0.40
	4S-½H	1.0	0.90	0.65	0.30	0.25
	4S-H	1.0	0.80	0.55	0.25	0.20
	17S-T	1.0	0.90	0.60	0.30	0.15
	A17S-T	1.0	0.90	0.60	0.30	0.15
	24S-T	1.0	0.85	0.70	0.40	0.20
	25S-W	1.0	1.00	0.75	0.30	0.15
	25S-T	1.0	0.90	0.60	0.25	0.10
	51S-W	1.0	1.00	0.80	0.30	0.15
	51S-T	1.0	0.75	0.55	0.20	0.10
	52S-O	1.0	0.95	0.90	0.70	0.55
	52S-¾H	1.0	0.95	0.80	0.50	0.30
	53S-O	1.0	0.80	0.60	0.50	0.30
	53S-T	1.0	0.85	0.70	0.40	0.15
CAST	12	1.0	1.00	0.95	0.85	0.60
	43	1.0	0.80	0.70	0.55	0.40
	112	1.0	1.00	0.95	0.85	0.60
	122-T2	1.0	0.90	0.85	0.75	0.60
	122-T61	1.0	0.90	0.80	0.50	0.20
	142	1.0	1.00	0.90	0.80	0.50
	142-T61	1.0	0.90	0.80	0.65	0.30
	195-T4	1.0	0.95	0.80	0.45	0.30
	214	1.0	0.95	0.90	0.75	0.50
	220-T4	1.0	0.85	0.75	0.50	0.30
	355-T4	1.0	1.00	0.90	0.50	0.20
	355-T6	1.0	0.95	0.85	0.55	0.25
	355-T51	1.0	0.90	0.80	0.50	0.20
	A355-T51	1.0	0.95	0.90	0.60	0.30
	A355-T59	1.0	0.90	0.85	0.70	0.35
	356-T4	1.0	0.95	0.85	0.50	0.30

TABLE 8—CONVERSION FACTORS

Weight of	Multiplied By	Gives Weight of Equal Volume of	Weight of	Multiplied By	Gives Weight of Equal Volume of
51S	2.92	Steel	2S	2.7	Tin
17S or 25S	2.82	Steel	2S	2.62	Zinc
24S	2.83	Steel	2S	1.01	3S
2S	2.89	Steel	2S	1.005	4S
2S	3.1	Brass	2S	1.03	17S or 25S
2S	3.3	Copper or Monel	2S	1.02	24S
			2S	0.985	52S
2S	3.26	Nickel	2S	0.99	51S or 53S

TABLE 9—CONDITIONS FOR HEAT TREATMENT OF ALUMINUM ALLOYS

(All Temperatures in Degrees Fahrenheit)

Alloy	Solution Heat Treatment				Precipitation Heat Treatment(4)		
	Temperature	Approximate Time of Heating	Quench(2)	Temper Designation	Temperature	Time of Aging	Temper Designation
17S	930–950	(1)	Cold water		Room	4 days(3)	17S-T
A17S	930–950	(1)	Cold water		Room	4 days(3)	A17S-T
24S	910–930	(1)	Cold water		Room	4 days(3)	24S-T
51S	960–980	(1)	Cold water	51SW	315–325	18 hours	51S-T
53S	960–980	(1)	Cold water	53SW	315–325	18 hours	53S-T

(1) In a molten nitrate bath, the time varies from 10 to 60 minutes depending upon the size of the load and the thickness of the material. In an air furnace, proper allowance must be made for a slower rate of bringing the load up to temperature. For heavy material a longer time at temperature may be necessary.

(2) It is essential that the quench be made with a minimum time loss in transfer from the furnace.

(3) More than 90 per cent of the maximum properties are obtained during the first day of aging.

(4) Precipitation heat treatment at elevated temperatures is patented.

TABLE 10—TYPICAL* MECHANICAL PROPERTIES OF WROUGHT ALUMINUM ALLOYS(1)

Alloy and Temper	TENSION: Yield Strength(2) (Set = 0.2%) Lbs. per Sq. In.	TENSION: Ultimate Strength Lbs. per Sq. In.	TENSION: Elongation(3) Per Cent in 2 In.: Sheet Specimen (1/16 Inch Thick)	TENSION: Elongation(3) Per Cent in 2 In.: Round Specimen (0.505 In. Diameter)	HARDNESS: Brinell 500 kg. 10 mm. Ball	SHEAR: Shearing Strength(4) Lbs. per Sq. In.	FATIGUE: Endurance Limit(5) Lbs. per Sq. In.
2S-O	4,000	13,000	35	45	23	9,500	5,000
2S-¼H	13,000	15,000	12	25	28	10,000	6,000
2S-½H	14,000	17,000	9	20	32	11,000	7,000
2S-¾H	17,000	20,000	6	17	38	12,000	8,000
2S-H	21,000	24,000	5	15	44	13,000	8,500
3S-O	5,000	16,000	30	40	28	11,000	7,000
3S-¼H	15,000	18,000	10	20	35	12,000	8,000
3S-½H	18,000	21,000	8	16	40	14,000	9,000
3S-¾H	21,000	25,000	5	14	47	15,000	9,500
3S-H	25,000	29,000	4	10	55	16,000	10,000
4S-O	10,000	26,000	20	25	45	16,000	14,000
4S-¼H	22,000	30,000	10	17	52	16,000	14,500
4S-½H	27,000	33,000	9	12	63	18,000	15,000
4S-¾H	31,000	37,000	5	9	70	20,000	15,500
4S-H	34,000	40,000	5	6	77	21,000	16,000
11S-T3	42,000	49,000	..	14	95	30,000	......
17S-O	10,000	26,000	20	22	45	18,000	11,000
17S-T	35,000	58,000	20	22	100	35,000	15,000
17S-RT	46,000	61,000	13	..	110	36,000	......
Alclad 17S-T	32,000	55,000	18	..	..	32,000	......
Alclad 17S-RT	40,000	57,000	11	..	..	32,000	......
A17S-O	8,000	22,000	24	27	38	15,000	......
A17S-T	24,000	43,000	24	27	70	25,000	13,500
24S-O	10,000	26,000	20	22	42	18,000	......
24S-T	43,000	65,000	20	22	105	40,000	14,000
24S-RT	53,000	68,000	13	..	116	41,000	14,500
Alclad 24S-T	40,000	60,000	18	..	..	39,000	......
Alclad 24S-RT	49,000	62,000	11	..	..	39,000	......
51S-O	6,000	16,000	30	35	28	11,000	6,500
51S-W	20,000	35,000	24	30	64	24,000	10,500
51S-T	38,000	48,000	14	16	95	30,000	10,500
52S-O	14,000	29,000	25	30	45	18,000	17,000
52S-¼H	26,000	34,000	12	18	62	20,000	18,000
52S-½H	29,000	37,000	10	14	67	21,000	19,000
52S-¾H	34,000	39,000	8	10	74	23,000	20,000
52S-H	36,000	41,000	7	8	85	24,000	20,500

TABLE 10—TYPICAL* MECHANICAL PROPERTIES OF WROUGHT ALUMINUM ALLOYS(1)—Continued

Alloy and Temper	TENSION				HARDNESS	SHEAR	FATIGUE
	Yield Strength(2) (Set = 0.2%) Lbs. per Sq. In.	Ultimate Strength Lbs. per Sq. In.	Elongation(3) Per Cent in 2 In.		Brinell 500 kg. 10 mm. Ball	Shearing Strength(4) Lbs. per Sq. In.	Endurance Limit(5) Lbs. per Sq. In.
			Sheet Specimen (1/16 Inch Thick)	Round Specimen (0.505 In. Diameter)			
53S-O	7,000	16,000	25	35	26	11,000	7,500
53S-W	20,000	33,000	22	30	65	22,000	10,000
53S-T	32,000	38,000	14	20	80	26,000	11,000

*For guaranteed minimum values, see Tables 13 to 17 and 19.

(1) Young's modulus of elasticity is approximately 10,300,000 pounds per square inch.

(2) Stress which produces a permanent set of 0.2 per cent of the initial gauge length. (American Society for Testing Materials Specification for Methods of Tension Testing, E 8-33.)

(3) Elongation values vary with the form and size of tension test specimen. Thin sheet has somewhat lower elongation than values for 1/16 inch sheet shown in table. Thicker material, from which standard round tension test specimens (0.505 inch diameter) are tested, may have lower elongation because of the effect of commercial flattening operations on this property.

(4) Single-shear strength values obtained from double-shear tests.

(5) Based on withstanding 500,000,000 cycles of completely reversed stress, using the R. R. Moore type of machine and specimen.

TABLE 11—MECHANICAL PROPERTIES OF SAND CAST ALUMINUM ALLOYS[1]

ALLOYS	Minimum Values for Specifications: Tension[3] Ultimate Strength Lbs. per Sq. In.	Minimum Values for Specifications: Tension[3] Elongation Per Cent in 2 Inches	Typical Values (Not Guaranteed): Tension[3] Yield Strength[2] (Set=0.2%) Lbs. per Sq. In.	Tension[3] Ultimate Strength Lbs. per Sq. In.	Tension[3] Elongation Per Cent in 2 Inches	Compression[6] Yield Strength[2] (Set=0.2%) Lbs. per Sq. In.	Compression[6] Ultimate Strength Lbs. per Sq. In.	Hardness Brinell 500 kg. 10 mm. Ball	Shear Shearing Strength [4] Lbs. per Sq. In.	Fatigue Endurance Limit[5] Lbs. per Sq. In.	Density Lbs. per Cu. In.
12 and 212	19,000	[8]	14,000	22,000	2.0	16,000	38,000	65	20,000	7,500	0.102
43	17,000	3.0	9,000	19,000	4.0	9,000	25,000	40	15,000	6,500	0.096
47[7]	24,000	5.0	11,000	26,000	8.0	12,000	28,000	50	18,000	6,000	0.095
108	19,000	1.5	17,000	21,000	2.0	21,500	43,000	60	20,000	8,500	0.099
109	21,000	[8]	18,000	24,000	1.5	23,500	45,000	75	20,000	10,000	0.105
112	19,000	[8]	14,000	22,000	2.0	24,000	44,000	70	20,000	8,500	0.103
122-T2	23,000	[8]	21,000	25,000	1.0	33,500	54,000	75	25,500	9,500	0.106
122-T61	30,000	[8]	30,000	36,000	1.0	40,500	80,000	100	29,500		0.106
142	23,000	[8]	24,000	28,000	1.0	34,000	52,000	85	24,000	8,000	0.101
142-T61	32,000	[8]		37,000	0.5	58,000	70,000	100	32,000	8,000	0.101
142-T571	29,000	[8]	28,000	30,000	0.5	30,000	77,000	85	27,000	8,000	0.101
195-T4	29,000	6.0	16,000	31,000	8.0	27,000	43,000	65	28,000	6,000	0.100
195-T6	32,000	3.0	22,000	36,000	4.0	29,000	48,000	80	30,000	6,500	0.100
195-T62	36,000	[8]	27,000	40,000	2.0	45,500	56,000	95	31,000	7,000	0.100
214	22,000	6.0	12,000	25,000	9.0	12,000	50,000	50	19,000	5,500	0.095
216	25,000	4.0	16,000	27,000	6.0	15,000	57,000	60	23,500		0.094
220-T4	42,000	12.0	25,000	44,000	13.0	23,500	72,500	75	33,500	7,000	0.092
A334	22,000	[8]	20,000	26,000	1.5	20,000	70,000	65	24,000		0.099

TABLE 11—MECHANICAL PROPERTIES OF SAND CAST ALUMINUM ALLOYS(1)—Continued

ALLOYS	Minimum Values for Specifications		TYPICAL VALUES (Not Guaranteed)								
	Tension(3)		Tension(3)			Compression(6)		Hardness	Shear	Fatigue	Density
	Ultimate Strength Lbs. per Sq. In.	Elongation Per Cent in 2 Inches	Yield Strength(2) (Set=0.2%) Lbs. per Sq. In.	Ultimate Strength Lbs. per Sq. In.	Elongation Per Cent in 2 Inches	Yield Strength(2) (Set=0.2%) Lbs. per Sq. In.	Ultimate Strength Lbs. per Sq. In.	Brinell 500 kg. 10 mm. Ball	Shearing Strength (4) Lbs. per Sq. In.	Endurance Limit(5) Lbs. per Sq. In.	Lbs. per Cu. In.
355-T4	27,000	4.0	20,000	30,000	5.0	25,000	65,000	60	30,000		0.097
355-T6	32,000	2.0	27,000	35,000	3.0	29,000	68,000	80	30,000		0.097
355-T51	25,000	(8)	23,000	28,000	1.5	24,000	52,000	60	21,000	6,500	0.097
A355-T51	25,000	(8)	24,000	28,000	1.5	24,000	54,000	65	21,000	8,000	0.099
A355-T59	23,000	(8)	21,000	25,000	2.0	21,000	52,000	60	20,000	8,000	0.099
356-T4	26,000	5.0	16,000	28,000	6.0	16,000	46,000	55	22,000		0.095
356-T6	30,000	3.0	22,000	32,000	4.0	21,000	48,000	70	23,000	8,000	0.095
356-T51	23,000	(8)	20,000	25,000	2.0	17,000	80,000	55	18,000	6,000	0.095
645	25,000	2.5	22,000	29,000	4.0	34,000	50,000	70	22,500	7,500	0.106

(1) Young's modulus of elasticity is approximately 10,300,000 pounds per square inch.
(2) Stress which produces a permanent set of 0.2 per cent of the initial gauge length. (American Society for Testing Materials Specification for Methods of Tension Testing, E 8-33.)
(3) Tension values determined from standard half inch diameter tensile test specimens individually cast in green sand molds and tested without machining off the surface. See page 51 "Design of Aluminum Alloy Castings".
(4) Single-shear strength values obtained from double-shear tests.
(5) Based on withstanding 500,000,000 cycles of completely reversed stress, using the R. R. Moore type of machine and specimen.
(6) Results of tests on specimens having an 1/r ratio of 16 to 20. All specimens failed by lateral bending.
(7) Properties of this alloy obtained by special foundry practice, called "modification".
(8) Not specified. The error in determining low elongations is comparable with the value being measured.

TABLE 12—PROPERTIES(1) OF ALUMINUM PERMANENT MOLD ALLOYS(3)

ALLOY	Approximate Composition—Per Cent of Alloying Elements; Aluminum and Normal Impurities Constitute Remainder						Minimum Ultimate Strength Pounds per Square Inch	Minimum Elongation Per Cent in 2 Inches	Brinell(2) Hardness	Typical Density Pounds per Cubic Inch
	Copper	Iron	Silicon	Zinc	Magnesium	Nickel				
43	...	..	5.0	..	...	..	21,000	2.5	45–55	0.097
A108	4.5	..	5.5	..	...	..	24,000	..	65–80	0.100
112	7.5	1.2	...	1.5	...	..	23,000	..	70–90	0.104
B113	7.5	1.2	1.5	..	...	..	24,000	..	70–90	0.103
C113	7.5	1.2	4.0	1.5	...	..	24,000	..	70–90	0.103
122–T52	10.0	1.2	...	..	0.2	..	27,000	..	95–125	0.104
122–T65	10.0	1.2	...	..	0.2	..	38,000	..	125–150	0.104
122–T551	10.0	1.2	...	..	0.2	..	30,000	..	125–150	0.104
122–T552	10.0	1.2	...	..	0.2	..	27,000	..	100–125	0.104
A132–T4	0.8	0.8	12.0	..	1.0	2.5	30,000	..	90–120	0.097
A132–T551	0.8	0.8	12.0	..	1.0	2.5	30,000	..	85–115	0.097
138	10.0	1.2	4.0	..	0.2	..	26,000	..	85–110	0.105
142	4.0	..	...	..	1.2	2.0	26,000	..	90–115	0.100
142–T61	4.0	..	...	..	1.2	2.0	40,000	..	100–130	0.100
142–T571	4.0	..	...	..	1.2	2.0	33,000	..	90–120	0.100
144	10.0	..	4.0	..	0.2	..	26,000	..	85–110	0.105
144–T4	10.0	..	4.0	..	0.2	..	36,000	..	100–130	0.105
B195–T4	4.5	..	2.8	..	...	..	33,000	4.5	70–90	0.101
B195–T62	4.5	..	2.8	..	...	..	42,000	..	90–110	0.101
D195–T4	5.5	..	0.7	..	...	..	35,000	5.0	60–80	0.102
A214	...	..	...	2.0	3.75	..	21,000	2.5	50–65	0.096
355–T4	1.2	..	5.0	..	0.5	..	31,000	4.5	70–85	0.097
355–T6	1.2	..	5.0	..	0.5	..	36,000	1.5	85–100	0.097

(1) Properties obtained from standard ½-inch diameter test specimens, individually cast in a permanent mold, and tested without machining off the surface. The compositions and/or heat treatment and the chill casting of many of these alloys are patented.

(2) Brinell limits obtained from tests on commercial castings. For 122 and 142 alloys, values apply to readings taken on piston head ½ inch from edge and ½ inch from gate on pistons having thickness of head up to ½ inch. Thicker castings, castings poured with sand core or poured in sand give lower values, the maximum decrease being about 20.

(3) Young's modulus of elasticity is approximately 10,300,000 pounds per square inch.

TABLE 13—MECHANICAL PROPERTIES SPECIFICATIONS FOR SHEET AND PLATE 2S, 3S, 4S, 52S

SHEET

Grade and Temper	Tensile Strength Lbs. per Sq. In. Minimum Except for Soft (O) Temper	Minimum Elongation**—Per Cent in 2 Inches								
		.250″–.204″	5–6 Gauge .203″–.162″	7–9 Gauge .161″–.114″	10–16 Gauge .113″–.051″	17–20 Gauge .050″–.032″	21–24 Gauge .031″–.020″	25–28 Gauge .019″–.013″	29–32 Gauge .012″–.008″	33–36 Gauge .007″–.005″
2SO	15,500*	30	30	30	30	25	20	15	15	15
2S¼H	14,000	10	10	10	9	7	5	4	..	..
2S½H	16,000	7	7	7	7	5	4	3	2	..
2S¾H	19,000	..	..	4	4	3	2	1	1	1
2SH	22,000	..	..	4	4	3	2	1	1	1
3SO	19,000*	25	25	25	25	23	20	20	18	16
3S¼H	17,000	9	9	8	7	6	5	4	..	..
3S½H	19,500	8	8	7	6	5	4	3	2	..
3S¾H	23,500	..	..	4	4	3	2	1	1	1
3SH	27,000	..	..	4	4	3	2	1	1	1
4SO	29,000*	18	18	18	18	16	14	10	..	..
4S¼H	27,000	7	7	7	6	5	4	2	..	..
4S½H	30,000	6	6	6	5	4	4	2	..	..
4S¾H	34,000	..	..	4	4	4	2	2	..	..
4SH	36,000	..	..	4	4	3	2	2	..	..
52SO	31,000*	20	20	20	20	20	18	15	..	..
52S¼H	31,000	10	10	10	8	6	6	5	..	..
52S½H	34,000	8	8	8	7	5	5	4	..	..
52S¾H	37,000	..	..	4	4	4	3	3	..	..
52SH	39,000	..	..	4	4	4	3	3	..	..

PLATE

2S, 3S, 4S, 52S, As Rolled—No physical tests required (See Table 33, Note (3).)

O, ¼H, ½H { Physical properties same as for ¼-inch sheet in same alloy and temper. (See Table 33 for temper available in various thicknesses.)

MAXIMUM AND MINIMUM COMMERCIAL THICKNESS OF FLAT AND COILED SHEET IN ALL TEMPERS

Temper	FLAT SHEET Thickness—Inches		COILED SHEET Thickness—Inches	
	Maximum	Minimum	Maximum	Minimum
O	0.250	0.010	0.102	0.005
¼H	0.250	0.016	0.102	0.025
½H	0.250	0.010	0.081	0.010
¾H	0.162	0.010	0.051	0.005
H	0.128	0.010	0.102	0.005

*Maximum. So specified to insure complete annealing.

**In the ¼H and ½H tempers, coiled sheet may have an elongation one per cent lower than the above values. Test specimens taken parallel to direction of rolling from flat and coiled sheet in ¼H and ½H tempers.

TABLE 14—MECHANICAL PROPERTIES SPECIFICATIONS FOR 17S ALLOY PRODUCTS

Material	Dimensions(1) (Inches)	Tensile Strength Pounds per Square Inch Minimum Except for 17S-O*	Yield Strength (Set=0.2%) Pounds per Square Inch Minimum	Elongation (Minimum) Per Cent in 2 inches or in 4D**
17S-O Sheet and Plate	0.010—0.500	35,000*	......	12
17S-T Sheet and Plate	0.010—0.020	55,000	32,000	15
	0.021—0.040	55,000	32,000	17***
	0.041—0.128	55,000	32,000	18
	0.129—0.258	55,000	32,000	15
	0.259—0.500	55,000	32,000	12
	0.501—1.250	55,000	32,000	10
17S-RT Sheet	0.020—0.031	55,000	42,000	10
	0.032—0.036	55,000	42,000	11
	0.037—0.188	55,000	42,000	12
Alclad 17S-O Sheet	0.010—0.032	30,000*	......	8
	0.033—0.064	30,000*	......	10
	0.065—0.250	30,000*	......	12
Alclad 17S-T Sheet and Plate	0.010—0.020	50,000	28,000	13
	0.021—0.128	50,000	28,000	16
	0.128—0.250	50,000	28,000	13
	0.251—0.500	50,000	28,000	11
Alclad 17S-RT Sheet	0.020—0.031	50,000	37,000	8
	0.032—0.036	50,000	37,000	9
	0.037—0.188	50,000	37,000	10
Wire, Rod, Bar and Shapes				
17S-O Wire	up to 0.124	35,000*	......	..
17S-O (Rolled or extruded)	0.125—8.000	35,000*	......	12
17S-T Wire	up to 0.124	55,000	......	..
17S-T Rounds, squares, hexagons, octagons, (rolled)	0.125—0.750	55,000	30,000	18
	0.751—3.000	53,000	30,000	18
	3.001—8.000	50,000	28,000	16
17S-T Rectangular bars	up to 0.750	53,000	30,000	16
	0.751—3.000	50,000	28,000	16
17S-T Structural shapes (rolled)	....	50,000	30,000	16
17S-T Extruded shapes	....	50,000	35,000	12

TABLE 14—MECHANICAL PROPERTIES SPECIFICATIONS FOR 17S ALLOY PRODUCTS—Continued

Material	Dimensions(1) (Inches)	Tensile Strength Pounds per Square Inch Minimum Except for 17S-O*	Yield Strength (Set=0.2%) Pounds per Square Inch Minimum	Elongation (Minimum) Per Cent in 2 inches or in 4D**
Tubing				
17S-O	All	35,000*	......	..
17S-T	¼—1 incl.	55,000	40,000	16
	over 1—1½ incl.	55,000	40,000	14
	over 1½—9 incl.	55,000	40,000	12
17S-RT	All	60,000	52,000	10
Forgings				
17S-T	up to 4	55,000	30,000	16

*Maximum. So specified to insure complete annealing.

**For wire, rod and bar the gauge length is four times the diameter or distance between parallel surfaces except when a flat test specimen is used.

***For sheets less than 30 inches wide, elongation shall be 18% in 2 in.

(1) For Sheet and Plate = Thickness.
For Wire, Rod and Bar = Diameter or least distance between parallel surfaces.
For Tubing = Outside Diameter.
For Forgings = Diameter or thickness.

TABLE 15—MECHANICAL PROPERTIES SPECIFICATIONS FOR 24S ALLOY PRODUCTS

Material	Dimensions[1] (Inches)	Tensile Strength Pounds per Square Inch Minimum Except for 24S-O*	Yield Strength (Set=0.2%) Pounds per Square Inch Minimum	Elongation Per Cent in 2 inches or in 4D** Minimum
Sheet and Plate				
24S-O	0.010—0.500	35,000*	......	12
24S-T	0.010—0.020	62,000	40,000	15
	0.021—0.128	62,000	40,000	17
	0.129—0.250	62,000	40,000	15
24S-RT	0.020—0.031	65,000	50,000	10
	0.032—0.036	65,000	50,000	11
	0.037—0.188	65,000	50,000	12
Alclad 24S-O	0.010—0.032	30,000*	......	8
	0.033—0.064	30,000*	......	10
	0.065—0.250	30,000*	......	12
Alclad 24S-T	0.010—0.020	56,000	37,000	13
	0.021—0.128	56,000	37,000	16
	0.129—0.250	56,000	37,000	13
Alclad 24S-RT	0.020—0.031	58,000	46,000	8
	0.032—0.040	58,000	46,000	9
	0.041—0.188	58,000	46,000	10
Wire, Rod, Bar and Shapes				
24S-O Wire	up to 0.124 incl.	35,000*	......	..
24S-O (Rolled or extruded)	0.125—8.000	35,000*	......	12
24S-T Rounds, square, octagons (rolled)	0.125—3.000	62,000	40,000	16
24S-T Rectangular bars	up to 3 x 4	62,000	40,000	14
24S-T Extruded shapes	....	57,000	42,000	12
Tubing				
24S-O	All	35,000*	......	..
24S-T	¼ to 1 incl.	62,000	40,000	16
	over 1—1½ incl.	62,000	40,000	14
	over 1½—8 incl.	62,000	40,000	12

*Maximum. So specified to insure complete annealing.
**For wire, rod and bar the gauge length is four times the diameter or distance between parallel surfaces except when a flat test specimen is used.
(1) For Sheet and Plate=Thickness.
For Wire, Rod and Bar=Diameter or least distance between parallel surfaces.
For Tubing=Outside Diameter.

TABLE 16—MECHANICAL PROPERTIES SPECIFICATIONS FOR 51S ALLOY PRODUCTS

Material	Dimensions(1) (Inches)	Tensile Strength Pounds per Square Inch Minimum Except for 51S-O*	Yield Strength (Set=0.2%) Pounds per Square Inch Minimum	Elongation Per Cent in 2 inches or in 4D** Minimum
Sheet and Plate				
51S-O	0.010—0.020	19,000*	......	20
	0.021—0.128	19,000*	......	22
	0.129—0.500	19,000*	......	25
51S-W	0.010—0.020	30,000	16,000	18
	0.021—0.250	30,000	16,000	20
	0.251—0.500	30,000	16,000	18
51S-T	0.010—0.020	45,000	35,000	8
	0.021—0.250	45,000	35,000	10
	0.251—0.500	45,000	35,000	8
Wire, Rod, Bar and Shapes				
51S-O Wire	up to 0.124 incl.	19,000*	......	..
51S-O All sections (rolled or extruded)	0.125—8.000	19,000*	......	20
51S-W Wire	up to 0.124 incl.	30,000	......	..
51S-W Rolled sections	0.125—3.000	30,000	16,000	16
51S-W Extruded sections	All sizes	26,000	16,000	14
51S-T Wire	up to 0.124 incl.	45,000	......	..
51S-T Rolled sections	up to 3.0	43,000	35,000	8
51S-T Extruded sections	All sizes	42,000	38,000	8
Tubing				
51S-O	¼—8	19,000*	......	..
51S-W	¼—8	30,000	16,000	14
51S-T	¼—8	45,000	35,000	8
Forgings				
	up to 4	40,000	30,000	8

*Maximum. So specified to insure complete annealing.
**For wire, rod and bar the gauge length is four times the diameter or distance between parallel surfaces (4D) except when a flat test specimen is used.
(1) See (1) page 73.

TABLE 17—MECHANICAL PROPERTIES SPECIFICATIONS FOR 53S ALLOY PRODUCTS

Material	Dimensions(1) (Inches)	Tensile Strength Pounds per Square Inch Minimum Except for 53S-O*	Yield Strength (Set=0.2%) Pounds per Square Inch Minimum	Elongation Per Cent in 2 inches or in 4D** Minimum
Sheet and Plate				
53S-O	0.010—0.032	19,000*	......	20
	0.033—0.128	19,000*	......	22
	0.129—0.500	19,000*	......	25
53S-W	0.010—0.020	28,000	16,000	18
	0.021—0.249	28,000	16,000	20
	0.250—0.500	28,000	16,000	18
53S-T	0.010—0.031	35,000	28,000	8
	0.032—0.500	35,000	28,000	10
Wire, Rod, Bar and Shapes				
53S-O Wire	up to 0.124	19,000*	......	..
53S-O (Rolled)	0.125—3.000	19,000*	......	20
53S-O Extruded	....	19,000*	......	18
53S-W Wire	up to 0.124	25,000	......	..
53S-W Rounds, squares, hexagons, octagons, rectangles (rolled)	0.125—3.000	25,000	14,000	20
53S-W Shapes (rolled or extruded)	....	25,000	14,000	18
53S-T Wire	up to 0.124	32,000	......	..
53S-T Rounds, squares, hexagons, octagons (rolled)	0.125—3.000	32,000	25,000	14
53S-T Rectangles (rolled)	up to 0.750	32,000	25,000	14
	0.751—3.000	32,000	25,000	14
53S-T Shapes (extruded or rolled)	....	32,000	25,000	10
53S-T5 (extruded)	All	22,000	16,000	10

TABLE 17—MECHANICAL PROPERTIES SPECIFICATIONS FOR 53S ALLOY PRODUCTS—Continued

Material	Dimensions[1] (Inches)	Tensile Strength Pounds per Square Inch Minimum Except for 53S-O*	Yield Strength (Set=0.2%) Pounds per Square Inch Minimum	Elongation Per Cent in 2 inches or in 4D** Minimum
Tubing				
53S-O	All	19,000*	......	..
53S-W	¼—1 incl.	28,000	14,000	18
	over 1—1½ incl.	28,000	14,000	20
	over 1½—8 incl.	28,000	14,000	18
53S-T	¼—1 incl.	35,000	28,000	16
	over 1—1½ incl.	35,000	28,000	14
	over 1½—8 incl.	35,000	28,000	12
Forgings				
53S-T	up to 4 inches	36,000	30,000	16

*Maximum. So specified to insure complete annealing.

**For wire, rod and bar the gauge length is four times the diameter or distance between parallel surfaces except when a flat test specimen is used.

(1)For Sheet and Plate=Thickness.
For Wire, Rod and Bar=Diameter or least distance between parallel surfaces.
For Tubing=Outside Diameter.
For Forgings=Diameter or thickness.

TABLE 18—CHEMICAL COMPOSITION AND TYPICAL MECHANICAL PROPERTIES(1) OF DIE-CASTING ALLOYS(2)

Alloy	Nominal Chemical Composition(3)			Ultimate Strength Lbs. per Sq. In.	Elongation Per Cent in 2 Inches
	Copper	Silicon	Nickel		
13	....	12.0	....	33,000	1.3
81	8.0	3.0	....	32,000	1.3
82	4.0	5.0	....	44,000	0.2
83	2.0	3.0	....	30,000	3.5
85	4.0	5.0	....	35,000	3.0
93	4.0	2.0	4.0	32,000	1.0

(1) Tensile properties are average of values obtained from A.S.T.M. standard round die-cast test specimen, ¼ inch in diameter. Brinell Hardness obtained from A.S.T.M. standard flat die-cast test specimen, ⅛ inch thick, using 125 kg. load and 5mm. ball.

(2) Young's modulus of elasticity for all of the above alloys is approximately 10,300,000 pounds per square inch.

(3) The composition and chill casting of many of these alloys are patented.

TABLE 19—MECHANICAL PROPERTIES SPECIFICATIONS FOR ALUMINUM ALLOY FORGINGS*

Alloy	Minimum Tensile Strength Pounds per Square Inch	Yield Strength (Set = 0.2%) Pounds per Square Inch Minimum	Minimum Elongation Per Cent in 2 Inches**	Brinell Hardness 500 kg.-10mm. ball Minimum
14S-T	65,000	50,000	10	130
17S-T	55,000	30,000	16	90
18S-T	55,000	35,000	8	90
25S-T	55,000	30,000	16	90
32S-T	52,000	40,000	5	110
51S-T	40,000	30,000	12	90
A51S-T	43,000	34,000	12	90
53S-T	36,000	30,000	16	75
70S-T	50,000	40,000	16	..

*Applies to forgings up to 4 inches in diameter or thickness.

**The gauge length for the measurement of elongation shall be four times the diameter of the test specimen in case a sub-size test specimen is used.

TABLE 20—COMMERCIAL TOLERANCES FOR SHEET AND PLATE ALL ALLOYS

Thickness Tolerances

FLAT SHEET—ALL ALLOYS; COILED SHEET—17S, ALCLAD 17S, 24S, ALCLAD 24S, 51S

Thickness		Tolerance (Plus or Minus) in inches except where shown as per cent of nominal thickness (T)					
B & S Gauge	Inches	Width Up to 18″ Incl.	Width Over 18″ to 36″ Incl.	Width Over 36″ to 54″ Incl.	Width Over 54″ to 72″ Incl.	Width Over 72″ to 90″ Incl.	Width Over 90″ to 102″ Incl.
3–8	0.249 to 0.129	4%T	4%T	5%T	6%T	7%T	8%T
9–10	0.128 to 0.092	0.004	0.0045	0.005	0.007	0.009	0.010
11–12	0.091 to 0.073	0.003	0.003	0.004	0.006	0.008	.....
13–16	0.072 to 0.051	0.0025	0.003	0.004	0.005	0.007	.....
17–18	0.050 to 0.037	0.002	0.0025	0.003	0.004	.....	.....
19–25	0.036 to 0.018	0.0015	0.002	0.0025	.....	.....	.....
26–30	0.017 to 0.010	0.0015	0.0015	0.002	.....	.....	.....

COILED SHEET 2S, 3S, 4S

Thickness		Tolerance (Plus or Minus) in inches		
B & S Gauge	Inches	Width Up to 12″ Incl.	Width* Over 12″ to 24″ Incl.	Width* Over 24″
10–11	0.102 to 0.091	0.003	0.003	0.004
12	0.090 to 0.073	0.003	0.003	0.003
13–16	0.072 to 0.051	0.0025	0.003	0.003
17	0.050 to 0.041	0.0025	0.0025	0.0025
18–20	0.040 to 0.030	0.002	0.0025	0.0025
21–24	0.029 to 0.019	0.002	0.002	0.002
25–29	0.018 to 0.011	0.0015	0.002	......
30–32	0.010 to 0.008	0.001	0.0015	......
33–34	0.007 to 0.006	0.001	0.001	......

*Tolerance applies up to Maximum Width shown in Table 31.

PLATE—ALL ALLOYS

Thickness (Inches)	Tolerance (Plus or Minus) in per cent of nominal thickness			
	Width Up to 54″ Incl.	Width Over 54″ to 72″ Incl.	Width Over 72″ to 90″ Incl.	Width Over 90″ to 120″ Incl.
3.000 to 1.001	3	3	4	5
1.000 to 0.501	4	4	5	6
0.500 to 0.375	5	5	6	7
0.374 to 0.250	5	6	7	8

TABLE 21—COMMERCIAL TOLERANCES FOR SHEET AND PLATE ALL ALLOYS

Width, Length, Diameter

FLAT SHEET—SHEARED

Width Tolerance (Plus or Minus), Inches

Thickness		Width 1/4″ to 4″ Incl.	Width Over 4″ to 18″ Incl.	Width Over 18″ to 36″ Incl.	Width Over 36″ to 54″ Incl.	Width Over 54″ to 72″ Incl.	Width Over 72″ to 102″ Incl.
B & S Gauge	Inches						
3–9	0.249 to 0.103	. .	3/32	1/8	3/16	3/16	1/4
10–34	0.102 to 0.006	1/32	1/16	3/32	1/8	5/32	3/16

Length Tolerance (Plus or Minus), Inches

Thickness	Length Up to 18″ Incl.	Length Over 18″ to 48″ Incl.	Length Over 48″ to 120″ Incl.	Length Over 120″ to 180″ Incl.	Length Over 180″ to 540″ Incl.
All Gauges	1/16	3/32	1/8	5/32	1/4

COILED SHEET—SHEARED

Width Tolerance (Plus or Minus), Inches

Thickness		Width 1/4″ to 3″ Incl.	Width Over 3″ to 24″ Incl.	Width Over 24″
B & S Gauge	Inches			
10 to 34	0.102 to 0.006	1/64	1/32	3/64

SHEET CIRCLES—SHEARED

Diameter Tolerance (Plus or Minus), Inches

Thickness	Diameter 5″ to 18″ Incl.	Diameter Over 18″
All Gauges	1/32	3/64

SHEET AND PLATE—SAWED

Dimension Tolerance (Plus or Minus), Inches

Thickness (Inches)	Dimensions Up to 10″ Incl.	Dimensions Over 10″ to 36″ Incl.	Dimensions Over 36″ to 60″ Incl.	Dimensions Over 60″ to 130″ Incl.
Up to 3	1/32	1/16	3/32	3/32

PLATE—SHEARED

Width and Length Tolerance (Plus only), Inches

Thickness* (Inches)	Width Tolerance**	Length Tolerance		
		Length Up to 12 ft.	Length Over 12 ft. to 20 ft.	Length Over 20 ft. to 45 ft.
1.500 to 1.001	5/8	5/8	11/16	3/4
1.000 to 0.501	1/2	1/2	9/16	5/8
0.500 to 0.250	3/8	3/8	7/16	1/2

*Capacity of plate shear varies with grade and temper of alloy. Maximum thickness for heat-treated alloys (T) is 0.625 inch, for other alloys, 1 inch. Thicker plate must be sawed.

**Maximum width, 130 inches. For thicknesses 0.250 to 0.375 inches the minimum width is 6 inches; for thicknesses 0.376 to maximum shearing thickness and lengths up to 10 feet, 8 inches minimum width; for longer plates, 18 inches is the minimum width of sheared plate; narrower widths must be sawed.

TABLE 22—COMMERCIAL TOLERANCES FOR EXTRUDED PRODUCTS

SHAPES

Cross-Sectional Tolerances

Dimensions—Inches	2S, 3S, 4S and 17S, 24S, 51S, 53S—Not Heat Treated Plus or Minus—Inches	17S, 24S, 51S, 53S Heat Treated Plus or Minus—Inches
0.000 to 0.125	.007	.010
0.126 to 0.500	.010	.015
0.501 to 1.000	.015	.020
1.001 to 2.000	.017	.025
2.001 to 3.000	.020	.030
3.001 to 4.000	.025	.035
4.001 to 5.000	.030	.040
5.001 to 6.000	.035	.045
6.001 to 7.000	.040	.050
7.001 to 8.000	.045	.055
8.001 to 9.000	.050	.060
9.001 to 10.000	.055	.065
10.001 to 11.000	.060	.070
11.001 to 12.000	.065	.080

ROUND, SQUARE, RECTANGULAR, HEXAGON

Dimensions—Inches	All Grades—As Extruded or Heat Treated Plus or Minus—Inches
up to 0.500	.007
0.501 to 1.000	.010
1.001 to 2.000	.012
2.001 to 3.000	.015
3.001 and over	.018

EXTRUDED AND DRAWN ROD

Dimensions—Inches	All Grades—As Extruded or Heat Treated Plus or Minus—Inches
0.375 to 0.500	.0015
0.501 to 1.000	.002
1.001 to 2.500	.0025

Length Tolerances

Length—Feet	Tolerance—Inches
Up to 13	—0, +⅛
Over 13	—0, +¼

Standard Structural Shapes, rolled or extruded, (Channels, I-beams, Angles, Z's and T's) in which the thickness of web, flange, or leg is not less than 0.140 inches are manufactured to a tolerance of 2½ per cent (plus or minus) on the nominal weight of the section. Actual weight shipped is invoiced.

TABLE 23—COMMERCIAL TOLERANCES FOR TUBING

1. ROUND TUBING

Diameter Tolerance

Nominal Diameter Inches	Tolerance in Inches (Plus or minus)		
	Mean Diameter* or Pi-tape measurement—2S, 3S, 17S, 24S, 51S, 52S, 53S	Individual Measurement of Diameter (out-of-roundness)	
		2S, 3S, 52S, except (1) Soft (O), or (2) thin wall** tubes	17S, 24S, 51S, 53S, 2S-O, 3S-O, 52S-O, and thin wall** tubes
3/8 to 1/2 incl.	0.003	0.003	0.006
Greater than 1/2 to 1 incl.	0.004	0.004	0.008
Greater than 1 to 2 incl.	0.005	0.005	0.010
Greater than 2 to 3 incl.	0.006	0.006	0.012
Greater than 3 to 5 incl.	0.008	0.008	0.016
Greater than 5 to 6 incl.	0.010	0.010	0.020
Greater than 6 to 8 incl.	0.015	0.015	0.030
Greater than 8 to 10 incl.	0.020	0.020	0.040

*Mean Diameter is the average of any two measurements of diameter taken at right angles to each other at any point along the length of the tube.
**Thin wall = less than 1/75 of diameter.

Wall Thickness Tolerance

Nominal Wall Thickness (T) (Inch)	Tolerance in Inches (Plus or minus)		
	Mean* Wall Thickness	Individual measurements of wall thickness	
	17S, 24S, 51S, 53S	17S, 24S, 51S, 53S	2S, 3S, 52S
0.010 to 0.035	0.002	10% of T	0.002
0.036 to 0.049	0.003	10% of T	0.003
0.050 to 0.120	0.004	10% of T	0.004
0.121 to 0.203	0.005	10% of T	0.005
0.204 to 0.300	0.008	10% of T	0.008
0.301 to 0.375	0.012	10% of T	0.012
0.376 to 0.500	0.032	10% of T	0.032

*Mean wall thickness is the average of the two measurements taken at opposite ends of any diameter of the tube.

Length Tolerances—All Alloys

Nominal Outside Diameter—Inches	Plus Tolerance in Inches	
	Lengths 2′ or Less	Lengths Over 2′
7/32 to 1/4 exclusive	1/8	1/4
1/4 to 2 inclusive	1/16	1/8
Greater than 2 to 3 inclusive	1/8	3/16
Greater than 3 to 10 inclusive	3/16	1/4

TABLE 23—COMMERCIAL TOLERANCES FOR TUBING—Continued

Straightness Tolerance—All alloys, all tempers except soft*

Outside Diameters* (Inches)	Tolerance
3/8 to 10	One part in 1200 parts of length, e.g., 0.1 inch in 10 feet

*Tubing in the soft temper or in diameters less than 3/8 inch is supplied commercially straight.

PIPE—STANDARD AND EXTRA HEAVY I. P. S.—2S, 3S

Size—Inches	O. D. Tolerance Inches	I. D. Tolerance Inches	Straightness	Length
1/8 to 1/2 incl.	+0.005,−0	+0,−0.003	Same as on commercial round tubing	Same as on commercial round tubing
Greater than 1/2 to 2 incl.	+0.008,−0	+0,−0.005		
Greater than 2 to 4 incl.	+0.010,−0	+0,−0.007		
Greater than 4 to 6 incl.	+0.012,−0	+0,−0.008		
Greater than 6 to 8 incl.	+0.014,−0	+0,−0.009		

TABLE 24—COMMERCIAL TOLERANCES OF ROLLED STRUCTURAL SHAPES; APPLICABLE TO SIZES AND SECTIONS INCLUDED IN TABLE 36

Dimensions	Tolerance
Thickness of Section	Plus or minus 2½ per cent of nominal thickness—minimum tolerance: ±0.010 inch.
Overall Dimensions. Length of leg of angles or Zees.	Plus or minus 2½ per cent of nominal—minimum tolerance ±1/16 inch.
Length	
Up to 20 feet, not inclusive.	Minus 0, Plus 1/4 inch.
20 feet to 30 feet, inclusive.	Minus 0, Plus 3/8 inch.
Over 30 feet.	Minus 0, Plus 1/2 inch.
Channels, overall width.	Plus 3/32 inch, minus 1/16 inch.
Channels, width of flange.	Plus or minus 4 per cent of nominal width.
Weight of a lot or shipment of sizes 3 inches or larger.	Plus or minus 2½ per cent of nominal weight.*

*Actual weight shipped is invoiced. For sizes smaller than 3 inches, dimension tolerances only apply.

TABLE 25—COMMERCIAL TOLERANCES FOR WIRE, ROD AND BAR—ALL ALLOYS

ROLLED ROD ROUND (ALL ALLOYS)

Diameter Inches	Tolerance—Inches		Diameter Inches	Tolerance—Inches	
	Plus	Minus		Plus	Minus
1.501 to 3.499	0.008	0.008	5.001 to 8.000	1/16	1/32
3.500 to 5.000	1/32	1/64			

ROLLED BAR (ALL ALLOYS)

(Squares, Hexagons†, Octagons†, Rectangles)

Least Distance Across Flats Inches	Tolerance—Inches Plus or Minus	Width (of Rectangles) Inches	Tolerance—Inches Plus or Minus
up to 0.500	0.006	up to 1.500	1/64
0.501 to 0.750	0.008	1.501 to 4.000	1/32
0.751 to 1.000	0.012	4.001 to 6.000	3/64
1.001 to 2.000	0.016	6.001 to 10.000	1/16
2.001 to 3.000	0.020		

COLD FINISHED WIRE, ROD AND BAR (ALL ALLOYS)

(Rounds, Squares, Hexagons, Octagons)

Rectangles up to 3.00″ wide (provided area is not greater than 3 square inches)

Diameter or Distance Across Flats Inches	Tolerance—Inches Plus or Minus		
	Rounds	Square Hexagons Octagons	Rectangles
up to 0.0359	0.0005	......	......
0.036 to 0.064	0.001	0.0015	0.0015
0.065 to 0.500	0.0015	0.002	0.002
0.501 to 1.000	0.002	0.0025	0.0025
1.001 to 1.500	0.0025	0.003	0.003
1.501 to 3.000	......	.....	0.005

COLD FINISHED RECTANGLES* 2S, 3S, 52S and 53S

Thickness Inches	Tolerance—Inches Plus or Minus	Width Inches	Tolerance—Inches Plus or Minus
up to 0.250	0.0025	2.000 to 4.000	1/32
0.251 to 0.500	0.0035		
0.501 to 0.750	0.005		
0.751 to 1.500	0.008		

*Widths greater than 3.00 inch and/or area greater than 3 square inches. Maximum dimensions 1.5 inch by 4 inch.
†Available in sizes greater than 1.5 inch; smaller sizes cold finished.

TABLE 25—COMMERCIAL TOLERANCES FOR WIRE, ROD AND BAR—ALL ALLOYS—Continued

CENTERLESS GROUND WIRE AND ROD, ROUND (ALL ALLOYS)

Diameter Inches	Tolerance—Inches Plus or Minus
0.0625 to 0.625	0.0005
0.626 to 1.500	0.001
1.501 to 2.500	0.0015

TABLE 26—COMMERCIAL TOLERANCES AND SIZES OF ROUGH ROLLED ROUND CORNER, SQUARES AND RECTANGLES—ALL ALLOYS

Size		Tolerance—Inches	
Thickness Inches	Width Inches	Thickness Plus or Minus	Width Plus or Minus
2 to 2.99 by	10⅛ to 16	1/32	¼
3 to 5.99 by	4 to 16	1/16	¼
6 to 8.00 by	6 to 12	1/16	¼

TABLE 27—COMMERCIAL TOLERANCES AND SIZES OF FLATTENED WIRE AND FLATTENED AND SLIT WIRE—ALL ALLOYS

Dimensions	Commercial Sizes Inches		Tolerance Inches Plus or Minus	Dimensions	Commercial Sizes Inches		Tolerance Inches Plus or Minus
	Minimum	Maximum			Minimum	Maximum	
FLATTENED WIRE (Round Edges)				FLATTENED AND SLIT WIRE (Slit Edges)			
Thicknesses	0.010	0.020	0.001	Thicknesses	0.010	0.020	0.001
	0.021	0.060	0.0015		0.021	0.060	0.0015
	0.061	0.187	0.002		0.061	0.080	0.002
Widths	0.030	0.875	0.007	Widths	0.125	0.625	0.0025
	0.876	2.000	0.010		0.626	1.500	0.004
					1.501	5.000	0.006

TABLE 28—MAXIMUM COMMERCIAL SIZES OF FLAT SHEET 2S AND 3S

Thickness Inches	Rolling Limits		Stretcher Limits		Diameter of Circle Inches	Temper Range
	Width Inches	Length Feet	Width Inches	Length Feet		
0.250–0.163	102	24	90	24	96	O to ½H
0.162–0.129	102	24	90	24	96	O to ¾H
0.128–0.126	102	24	90	24	96	O to H
0.125–0.094	102	24	88	24	96	O to H
0.093–0.064	90	24	86	24	90	O to H
0.063–0.040	84 76 60	16 20 30	76	20	84	O to H
0.039–0.032	66 60	14 20	*	*	66	O to H
0.031–0.020	60 54	10 16	*	*	60	O to H
0.019–0.014	48	12	*	*	48	O to H**
0.013–0.010	36	12	*	*	36	O to H**
0.009–0.005	30	8	*	*	30	O to H

*Greater than rolling limits.

**The minimum thickness for sheet in the ¼H temper is 0.016 inch.

TABLE 29—MAXIMUM COMMERCIAL SIZES OF STRONG ALLOY FLAT SHEET 17S, 24S*, 51S, 53S, ALCLAD 17S, AND ALCLAD 24S*—O, W, AND T TEMPER

Thickness Inches	Width Inches	Length Feet	Diameter Inches	Stretcher Maximum
.250 to .126 inclusive	102	24	96	90″ x 24′
.125 to .094 inclusive	102	24	96	88″ x 24′
.093 to .064 inclusive	90	24	90	86″ x 24′
.063 to .051 inclusive	72	18	72	76″ x 20′
.050 to .040 inclusive	60	18	60	76″ x 20′
.039 to .032 inclusive	48	18	48	76″ x 20′
.031 to .020 inclusive	42	16	42	76″ x 20′
.019 to .014 inclusive	36	14	36	76″ x 20′
.013 to .010 inclusive	28	14	28	76″ x 20′

*Widths greater than 60″ not strictly commercial in 24S and Alclad 24S; orders for greater widths in thicknesses 0.051″ to 0.250″ may be accepted tentatively, contingent upon the development of satisfactory commercial manufacturing practice.

Maximum size annealed sheet 96″ x 24′.

TABLE 30—MAXIMUM COMMERCIAL† SIZES OF FLAT SHEET 4S AND 52S

Thickness Inches	Rolling Limits		Stretcher Limits**		Diameter Inches	Temper Range
	Width Inches††	Length Feet	Width Inches	Length Feet		
0.250–0.163	102	24	90	24	96	O to ½H
0.162–0.129	102	24	90	24	96	O to ¾H
0.128–0.126	102	24	90	24	96	O to H
0.125–0.094	90	24	88	24	90	O to H
0.093–0.081	84	24	*	*	84	O to H
0.080–0.064	72	20	*	*	72	O to H
0.063–0.040	60	14	*	*	60	O to H
0.039–0.032	48	14	*	*	48	O to H
0.031–0.022	42	12	*	*	42	O to H
0.021–0.014	36	10	*	*	36	O to H***
0.013–0.010	28	8	*	*	28	O to H***

*Greater than rolling limits.
**Sheet harder than ½H cannot be stretched.
***The minimum thickness for sheet in the quarter hard (¼H) temper is 0.016 inch.
†Widths greater than 60 inches and/or weights of a single sheet greater than 200 pounds are not strictly commercial in 52S alloy; orders for sheets greater than these limits may be accepted tentatively, contingent upon development of satisfactory manufacturing practice.
††Maximum width of sheets in the hard temper (H) is 54 inches and in the three-quarter hard temper (¾H), 60 inches.

TABLE 31—MAXIMUM COMMERCIAL SIZES OF COILED SHEET 2S, 3S, AND 4S

Supplied in coils, flattened and cut to length**, or in circles.

Thickness (Inches)	Width (Inches)	Available Tempers
0.102–0.048	42	O to H
0.047–0.030	42*	O to H
0.029–0.024	38*	O to H
0.023–0.019	38	O, ½H, ¾H, H
0.018–0.012	36	O, ½H, ¾H, H
0.011–0.010	30	O, ½H, ¾H, H
0.009–0.0085	30	O, ¾H, H
0.008–0.0075	18	O, ¾H, H
0.007–0.005	14	O, ¾H, H

*In the ¼H temper the maximum width is 4 inches less than this value which applies to all other tempers.
**Flattened coiled sheet is not supplied in thickness greater than 0.081 inch.

TABLE 32—MAXIMUM COMMERCIAL SIZES
Flat Sheet 17S-RT, 24S-RT, Alclad 17S-RT and Alclad 24S-RT

Thickness Inches	Width (Inches)	
	Lengths up to 14 feet	Lengths 14 feet to 18 feet
0.188–0.078	30	..
0.077–0.043	30	24
0.042–0.030	24	20
0.029–0.020	24	..

TABLE 33—MAXIMUM COMMERCIAL SIZES—AVAILABLE TEMPERS—2S, 3S, 4S PLATE

Thickness Inches	Width Inches	Length Feet	Tempers
2″ and over	130(1)	30(4)	As Rolled(3) and O(2)
Less than 2″ to 1″	130(1)	30(4)	As Rolled(3), O(2), and ¼H
Less than 1″ to ¼″	120(1)	30(4)	As Rolled(3), O(2), ¼H and ½H

(1) The maximum diameter of circles in the O, ¼H and ½H tempers is 96 inches. In the as-rolled temper, in thicknesses less than 1 inch to ¼ inch, the maximum diameter is 120 inches, and in thicknesses 1 inch to 2 inches, the maximum diameter is 130 inches.

(2) Maximum size of annealed plate: 96 inches by 25 feet.

(3) As a result of the cooling of the plate while it is being rolled, there is some strain hardening of the metal, particularly in the thinner gauges. The average tensile properties of as-rolled plate in thicknesses up to ⅝ inch are approximately the same as those of quarter hard plate. As the thickness increases, the properties approach those of the soft temper (O).

(4) Subject to the limitation that the maximum weight of an individual plate or circle is 2,000 pounds.

NOTE: Flatness—
Stretcher-leveled plate is supplied in thicknesses ¼ inch to 1 inch, widths up to 90 inches, and lengths up to 38 feet.
Plate wider or longer than the limits for stretcher-leveled plate in thicknesses ¼ inch to 1 inch is supplied roller-leveled.
Plate in dimensions greater than the stretcher- and roller-leveler limits (i.e., thickness greater than 1 inch is supplied as flat as can be obtained from the rolls).

TABLE 34—MAXIMUM COMMERCIAL SIZES—STRONG ALLOY 17S, 51S, AND 53S PLATE

Thickness Inches	Width Inches	Length Feet	Diameter Inches	Stretcher Maximum	Tempers
2.500 to 1.001	120	35 (4) (5)	96	....	O(2), H, T, W(6)
1.000 to 0.375	120	35 (4) (5)	96	90″ x 24′	O(2), H, T, W(6)
0.374 to 0.250	108	34 (4) (5)	96	90″ x 24′	O(2), H, T, W(6)

(5) Narrower widths can be obtained in longer lengths but should be taken up with the nearest sales office.

(6) Maximum size of artificially aged plate (51S-T and 53S-T) is 98 inches by 36 feet.

Note on Flatness and Notes (2) and (4) of Table 33 apply also to this table.

TABLE 35—MAXIMUM COMMERCIAL SIZES OF ALCOA TREAD PLATE—STRETCHER LEVELED—3S, 4S, 17S AND 53S ALLOYS(1)

Thickness Inches	Maximum Size		Approximate Weight per Sq. Ft. Pounds(2)	Estimated Weight per Sq. Ft. in Steel Pounds
	Width Inches	Length Feet		
1/8	50	24	1.96	5.69
3/16	60	24	2.84	8.23
1/4	60	24	3.72	10.79
5/16	60	24	4.60	13.32
3/8	60	24	5.48	15.89

(1) Alcoa Tread Plate can be furnished in 17S, 4S, 3S and 53S alloys. Tread Plate in 17S is furnished only in the heat-treated temper (17S-T); in 4S it is furnished as rolled. Where maximum strength is desired, 17S or 53S are recommended.

(2) Values are for 3S and 4S. Multiply by 1.02 for 17S, and 0.98 for 53S.

TABLE 36—CONDENSED LIST OF COMMERCIAL SIZES OF 17S STRUCTURAL SHAPES

EQUAL ANGLES	UNEQUAL ANGLES		STRUCTURAL CHANNELS	TEES
Size Inches	Size Inches	Size Inches	Depth Inches	Size, Inches Flange Stem
			3	
7/16 x 7/16	3/4 x 3/8	2 1/2 x 1 1/2	4	1 x 1
1/2 x 1/2	1 x 3/4	2 1/2 x 2	5	1 1/2 x 1 1/4
5/8 x 5/8	1 13/64 x 3/4	3 x 1 1/2	6	1 1/2 x 1 1/2
3/4 x 3/4	1 1/4 x 3/4	3 x 2	7	
			8	
1 x 1			9	
1 1/4 x 1 1/4	1 1/4 x 1	3 x 2 1/2	10	2 x 2
1 1/2 x 1 1/2	1 1/2 x 1	3 1/2 x 2 1/2	12	2 1/4 x 2 1/4
1 3/4 x 1 3/4	1 1/2 x 1 1/4	3 1/2 x 3	CAR CHANNELS	2 1/2 x 1 1/4
	1 3/4 x 1 1/8	4 x 3		
			5	
2 x 2			6	
2 1/2 x 2 1/2	1 3/4 x 1 1/4	4 x 3 1/2	10	3 x 2 1/2
	2 x 1 1/4	5 x 2 1/2	I-BEAMS	3 x 3
3 x 3			3	4 x 4
3 1/2 x 3 1/2			4	
	2 x 1 3/8	5 x 3	5	
	2 x 1 1/2	5 x 3 1/2	6	ZEES
4 x 4			7	Depth, Inches
			8	3
5 x 5	2 1/4 x 1 1/2	6 x 3 1/2	H-BEAMS	4
			4	4 1/16
			5	4 1/8
6 x 6	2 1/2 x 1 1/4	6 x 4	6	5 1/16
			8	

Many of the above sections are obtainable in several different flange, web, or stem thicknesses. Consult nearest sales office.
Elements of sections are given in "Structural Aluminum Handbook" published by Aluminum Company of America.
Above list includes both Extruded and Rolled shapes.
Maximum length in a heat-treated alloy—Extruded Shape 36 Feet
—Rolled Shape 85 Feet

TABLE 37—RANGE OF COMMERCIAL SIZES OF ROUND TUBING

Thickness		Minimum O.D. Inches	Maximum O.D., Inches						
Stubs Gauge	Inches	2S, 3S, 17S, 24S, 51S, 52S, 53S	2S-O, 3S-O, 51S-O, 52S-O, 53S-O	17S-O, 24S-O	2S-1/4H 3S-1/4H 52S-1/4H	2S-1/2H 3S-1/2H 52S-1/2H	2S-3/4H 3S-3/4H 52S-3/4H	2S-H 3S-H 52S-H	17S-T, 24S-T, 51S-T, 53S-T
..	.500	2 3/4	7 1/4	7 1/4	9	7 3/4	5	3 3/4	9 1/2
..	.484	2 3/4	7 15/32	7 15/32	9 7/32	7 23/32	5 1/4	4	9 15/32
..	.480	2 1/2	7	7	7	7	5 1/4	4	7
..	.468	2 1/2	7 3/4	7 3/4	9 1/2	8 1/4	5 1/2	4	10
..	.453	2 1/2	7 31/32	7 31/32	9 15/32	8 7/32	5 1/2	4 1/4	9 15/32
..	.450	1 1/2	7	7	7	7	5 1/2	4 1/4	7
..	.437	1 1/2	8 1/4	8 1/4	10	8 1/2	5 1/2	4 1/4	10 3/4
..	.421	1 1/2	8 15/32	8 15/32	10 15/32	8 31/32	5 1/2	4 1/4	11 5/32
..	.406	1 1/2	8 3/4	8 3/4	10 3/4	9	6	4 1/2	11 1/8
..	.400	1 1/2	7	7	7	7	6	4 1/2	7
..	.390	1 1/2	8 31/32	8 31/32	11 1/32	9 15/32	6	4 1/2	11 1/32
..	.375	1 3/8	10	10	11	10 1/4	6 1/4	4 3/4	11
..	.359	1 3/8	9 31/32	9 31/32	10 29/32	10 15/32	6 1/4	5 1/4	10 29/32
..	.350	1 3/8	7	7	7	7	6 1/2	5 1/4	7
..	.344	1 3/8	10	10	10 7/8	10 7/8	6 1/2	5 1/4	10 7/8
..	.328	1 3/8	10 15/32	10 15/32	10 25/32	10 25/32	7 7/32	5 1/2	10 25/32
..	.320	1	7	7	7	7	7	5 1/2	7
..	.312	1	10 3/4	10 3/4	10 3/4	10 3/4	7 1/2	5 1/2	10 3/4
1	.300	7/8	7	7	7	7	7	6	7
..	.297	7/8	10 21/32	10 21/32	10 21/32	10 21/32	7 23/32	6	10 21/32
2	.284	7/8	7	7	7	7	7	6 1/4	7
..	.281	7/8	10 5/8	10 5/8	10 7/8	10 7/8	8 1/4	6 1/4	10 7/8
..	.266	7/8	10 17/32	10 17/32	10 25/32	10 25/32	8 23/32	6 1/2	10 25/32
3	.259	3/4	7	7	7	7	7	6 3/4	7
..	.250	3/4	10 3/4	10 3/4	10 3/4	10 3/4	9 1/4	7	10 3/4
4	.238	5/8	7	7	7	7	7	7	7
..	.234	5/8	10 21/32	10 21/32	10 21/32	10 21/32	9 15/32	7 15/32	10 21/32
5	.220	5/8	7	7	7	7	7	7	7
..	.218	5/8	10 5/8	10 5/8	10 5/8	10 5/8	10 3/8	8	10 5/8
6	.203	9/16	10 17/32	10 17/32	10 17/32	10 17/32	10 9/32	8 15/32	10 17/32
..	.187	9/16	10 1/2	10 1/2	10 1/2	10 1/2	10 1/4	9 1/4	10 1/2
7	.180	1/2	7	7	7	7	7	7	7
..	.171	1/2	10 13/32	10 13/32	10 13/32	10 13/32	10 3/8	9 31/32	10 13/32
8	.165	7/16	7	7	7	7	7	7	7
..	.156	7/16	10 3/8	10 3/8	10 3/8	10 3/8	10 3/8	10	10 3/8
9	.148	3/8	7	7	7	7	7	7	7

TABLE 37—RANGE OF COMMERCIAL SIZES OF ROUND TUBING —Continued

Thickness		Minimum O.D. Inches	Maximum O.D., Inches						
Stubs Gauge	Inches	2S, 3S, 17S, 24S, 51S, 52S, 53S	2S-O, 3S-O, 51S-O, 52S-O, 53S-O	17S-O, 24S-O	2S-¼H 3S-¼H 52S-¼H	2S-½H 3S-½H 52S-½H	2S-¾H 3S-¾H 52S-¾H	2S-H 3S-H 52S-H	17S-T, 24S-T, 51S-T, 53S-T
..	.140	3/8	10 9/32	9 15/32	10 9/32	10 9/32	10 9/32	9 31/32	9 15/32
10	.134	5/16	7	7	7	7	7	7	7
..	.125	5/16	10 1/4	8 3/4	10 1/4	10 1/4	10 1/4	10 1/4	8 3/4
11	.120	1/4	7	7	7	7	7	7	7
12	.109	1/4	9 15/32	8 23/32	9 15/32	9 15/32	9 15/32	9 15/32	8 23/32
13	.095	1/4	7	7	7	7	7	7	7
..	.093	1/4	9 1/4	8 1/4	9 1/4	9 1/4	9 1/4	9 1/4	8 1/4
14	.083	3/16	7	7	7	7	7	7	7
..	.078	3/16	8 31/32	7 23/32	8 31/32	8 31/32	9	9	7 23/32
15	.072	3/16	7	6 3/4	7	7	7	7	6 3/4
16	.065	3/16	7	6 3/4	7	7	7	7	6 3/4
..	.062	3/16	9	6 3/4	9	9	9	9	6 3/4
17	.058	3/16	7	6 1/4	7	7	7	7	6 1/4
18	.049	1/8	7	5	7	7	7	7	5
..	.046	1/8	8 31/32	3 3/4	8 31/32	8 31/32	8 31/32	8 31/32	3 3/4
19	.042	1/8	6 3/4	3 3/4	6 3/4	6 3/4	6 3/4	6 3/4	3 3/4
20	.035	3/32	5	3 1/4	5	5	5	5	3 1/4
21	.032	3/32	4	2 3/4	4	4	4	4	2 3/4
22	.028	3/32	4	2 3/4	4	4	4	4	2 3/4
23	.025	1/16	3 1/2	2 1/2	3 1/2	3 1/2	3 1/2	3 1/2	2 1/2
24	.022	1/16	3	2	3	3	3	3	2
25	.020	1/16	2 3/4	1 3/8	2 3/4	2 3/4	2 3/4	2 3/4	1 3/8
26	.018	1/16	2 1/2	9/16	2 1/2	2 1/2	2 1/2	2 1/2	9/16
27	.016	1/16	1 1/4	7/16	1 1/4	1 1/4	1 1/4	1 1/4	7/16
28	.014	1/16	1	3/8	1	1	1	1	3/8
29	.013	1/16	1	5/16	1	1	1	1	5/16
30	.012	1/16	5/8	1/4	5/8	5/8	5/8	5/8	1/4
31	.010	1/16	9/16	3/16	9/16	9/16	9/16	9/16	3/16
32	.009	1/16	1/2	1/8	1/2	1/2	1/2	1/2	1/8

TABLE 38—RANGE OF COMMERCIAL SIZES OF WIRE, ROD AND BAR

2S, 3S, 17S, 24S, 51S, 52S, AND 53S

COMMODITY	SMALLEST	LARGEST
	Diameter Inches	Diameter Inches
Round Wire—Drawn	36 ga.	0.374
Round Rod—Cold Finished	3/8	1 1/2
Round Rod—Rolled	3/8	8
	Distance Across Flats, Inches	Distance Across Flats, Inches
Square Wire—Drawn	1/32 x 1/32	11/32 x 11/32
Square Bar—Cold Finished*	3/8 x 1 1/2	2 x 2
Hexagonal Wire—Drawn	1/32	11/32
Hexagonal Bar—Cold Finished*	3/8	1 7/8
Octagonal Wire—Drawn	1/4	1/4
Octagonal Bar—Cold Finished	3/8	1 3/16
	Dimensions Inches	Dimensions Inches
Square Edge Rectangular Wire—Drawn	1/16 x 1/8	1/4 x 5/16
Square Edge Rectangular Bar, Common Alloy—Cold Finished	1/16 x 3/8	1 1/2 x 4
Square Edge Rectangular Bar, Strong Alloy—Cold Finished	1/16 x 3/8	†
Square Edge Rectangular Bar—Rolled	1/8 x 5/8	3 x 10
Round Edge Rectangular Bar—Rolled	.093 x 1 1/8	1/2 x 6
	Dimensions Inches	Dimensions Inches
Half Round Wire—Drawn	1/32 x 1/16	3/32 x 3/16
Half Oval Wire—Rolled	3/64 x 1/8	3/64 x 3/16
Oval Bar—Cold Finished	7/32 x 7/16	7/32 x 7/16
Half Oval Bar—Rolled	1/4 x 1	1/4 x 1 3/4

*A few of the larger sizes are rolled.
†Widths up to 3.0 inches, provided cross-sectional area is not greater than 3 square inches.

The above table indicates the range of commercial sizes. Intermediate sizes are not all available. See Table 27 for sizes of flattened wire and flattened and slit wire.

TABLE 39—APPROXIMATE TEMPERS OF ROLLED BAR, ROD AND SHAPES—2S, 3S, 52S†

Shape	Diameter or Least Distance Across Flats (Inches)	Approximate Temper*	
		Rolled	Cold Finished
Rounds, Squares, Hexagons, Octagons	Up to ¾″ inclusive	½H	½H to ¾H
	Greater than ¾″ to 1½″	¼H to ½H	½H to ¾H
	Greater than 1½″ to 3″	¼H	¼H to ½H
	Greater than 3″ to 8″	⅛H to ¼H	⅛H to ¼H
Rectangles	Up to ⅛″ inclusive	¼H to ½H	½H to ¾H
	Greater than ⅛″ to ½″	¼H to ½H	½H
	Greater than ½″ to 1½″	¼H	¼H
	Greater than 1½″ to 3″	⅛H to ¼H	⅛H to ¼H
Structural Shapes	Standard Sizes	¼H to ½H	

*Tempers shown are *approximate.* Minimum tensile strengths are not guaranteed, but experience indicates that the tempers shown for various commodities may normally be expected. The small sizes tend to run harder than the large sizes, since they finish colder from the rolls; also, cold finishing introduces a greater percentage of reduction in cross-sectional area, hence more strain hardening. *Typical* or *average* properties (*not minimum*) for the various alloys in the various tempers are shown in Table 10.

†52S is not produced in shapes.

INDEX

ALUMINUM COMPANY OF AMERICA

Sales Offices

ALBANY, N. Y.	90 State Street
ATLANTA, GA.	1818 Rhodes-Haverty Building
BOSTON, MASS.	20 Providence Street, Park Square
BUFFALO, N. Y.	1880 Elmwood Avenue
CHICAGO, ILL.	520 N. Michigan Avenue
CINCINNATI, OHIO	Times Star Building
CLEVELAND, OHIO	2210 Harvard Avenue
DETROIT, MICH.	3311 Dunn Road
FAIRFIELD, CONN.	Boston Post Road
HARTFORD, CONN.	Capitol Building, 410 Asylum Street
INDIANAPOLIS, IND.	716 Merchants Bank Building
KANSAS CITY, MO.	2306 Power & Light Building
LOS ANGELES, CALIF.	1031 S. Broadway
MILWAUKEE, WIS.	735 N. Water Street
MINNEAPOLIS, MINN.	1345 Northwestern Bank Building
NEWARK, N. J.	1111 Academy Building
NEW ORLEANS, LA.	815 American Bank Building
NEW YORK, N. Y.	230 Park Avenue
PHILADELPHIA, PA.	2307 Fidelity-Philadelphia Trust Building
PITTSBURGH, PA.	Gulf Building
SAN FRANCISCO, CALIF.	709 Rialto Building
ST. LOUIS, MO.	1825 Boatmen's Bank Building
SEATTLE, WASH.	1005 White Building
TOLEDO, OHIO	915 Ohio Bank Building
WASHINGTON, D. C.	606-612 Southern Building

ALCOA ALUMINUM

The word "Alcoa" and the adjacent design are registered trademarks applied to the products of Aluminum Company of America, whose technical staff exercises the most rigid control over every process in the production of Alcoa Aluminum . . . from the mining of bauxite ore to the production of uniform and high quality aluminum and aluminum alloys, in every commercial form.

ALCOA ALUMINUM

Form No. AD51e 15M 5-36
Wire-O Binding, Patents Pending

Printed in U.S.A.
THE EDDY PRESS CORPORATION
PITTSBURGH, PA.